GOLDER

REPORT

Supporting Information for an Alternative Liner System Demonstration

Great River Energy - Coal Creek Station

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1.0 INTRODUCTION

Great River Energy (GRE) operates two surface impoundments for storage of coal combustion residuals (CCRs) at Coal Creek Station, a 1,200-megawatt coal-fired electric generating plant located near Underwood, North Dakota. These surface impoundments, which are known as Ash Pond 91 and Ash Pond 92[1], have liner systems that were constructed in 1993 and 1989, respectively. Ash Pond 91 and Ash Pond 92 classify as existing surface impoundments under the Code of Federal Regulations Title 40 Part 257 (40 CFR 257, also known as the CCR Rule) and are permitted and regulated at the state level by the North Dakota Department of Health (NDDH) as surface impoundments under North Dakota Administrative Code Chapter 33.1-20-07.1. The locations of Ash Pond 91 and Ash Pond 92 are shown on Figure 1.

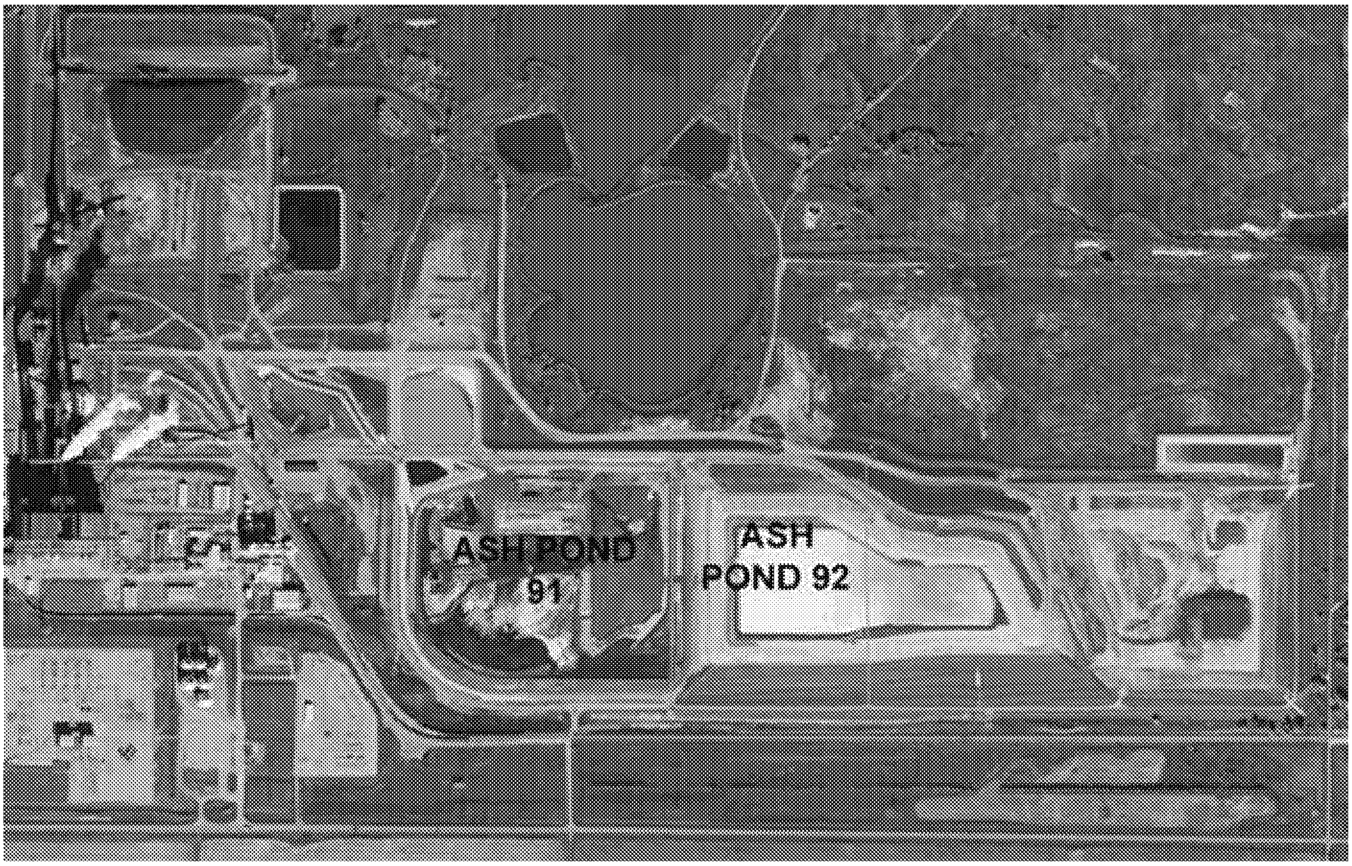

Figure 1: Ash Pond 91 and Ash Pond 92 Locations

The liner system designs for Ash Pond 91 and Ash Pond 92 were approved by the NDDH prior to construction. The liner systems were constructed with high-density polyethylene (HDPE) geomembrane having a thickness of 40 mils (0.040 inches) as the upper component of a composite liner system. The lower component is a compacted soil layer at least two feet thick with a hydraulic conductivity less than 1×10^{-7} centimeters per second (cm/sec). A

[1] Ash Pond 91 is referred to as Upstream Raise 91 in documents prepared for CCR Rule compliance. Ash Pond 92 is the western portion of the facility referred to as Upstream Raise 92 in documents prepared for CCR Rule compliance. Only this western portion of Upstream Raise 92 includes the use of 40-mil HDPE geomembrane, so the nomenclature "Ash Pond 92" is used in this report. The nomenclature "Ash Pond 91" is used for consistency.

rigorous construction quality assurance (CQA) program was carried out during installation of each composite liner system.

The CCR Rule, as published in April 2015, includes liner system design criteria that are meant to establish whether an existing CCR surface impoundment is considered to be "lined," and therefore not subject to closure requirements for "unlined" surface impoundments. Under these criteria, a lined surface impoundment must have one of the following:

- "A liner consisting of a minimum of two feet of compacted soil with a hydraulic conductivity of no more than $1x10^{-7}$ cm/sec" [40 CFR 257.71(a)(1)(i)] or
- A composite liner system with "the upper component consisting of, at a minimum, a 30-mil geomembrane liner (GM), and the lower component consisting of a two-foot layer of compacted soil with a hydraulic conductivity of no more than $1x10^{-7}$ cm/sec. GM components consisting of high density polyethylene (HDPE) must be at least 60-mil thick" [40 CFR 257.70(b), as referenced from 40 CFR 257.71(a)(1)(ii)] or
- An alternative composite liner system with "the upper component consisting of, at a minimum, a 30-mil GM, and a lower component, that is not a geomembrane, with a liquid flow rate no greater than the liquid flow rate of two feet of compacted soil with a hydraulic conductivity of no more than $1x10^{-7}$ cm/sec. GM components consisting of high density polyethylene (HDPE) must be at least 60-mil thick" [40 CFR 257.70(c), as referenced from 40 CFR 257.71(a)(1)(iii)].

A recent court decision issued by the United States Court of Appeals for the District of Columbia Circuit (No. 15-1219, decided August 21, 2018) vacated the portion of the CCR Rule allowing for a liner system consisting solely of two feet of compacted soil with a hydraulic conductivity of no more than $1x10^{-7}$ cm/sec [40 CFR 257.71(a)(1)(i)]. As a result, the composite liner system described in 40 CFR 257.70(b) is currently the only liner system that is specified under the CCR Rule. The composite liner systems for Ash Pond 91 and Ash Pond 92 do not strictly meet the requirements of 40 CFR 257.71(a)(1)(ii) because the thickness of the HDPE geomembrane (installed in 1989 and 1993) is 40 mils, rather than 60 mils or greater.

The option to demonstrate the appropriateness of an alternative composite liner system is provided under 40 CFR 257.71(a)(1)(iii), but only alternatives to the lower component of the composite liner system are considered. That is, no provision is included for alternatives to the upper component (i.e., the geomembrane), since the description of the upper component in an alternative composite liner system is identical to the description of the upper component in the prescriptive composite liner system. Thus, in what is likely an unintended consequence of the court decision, Ash Pond 91 and Ash Pond 92 could be considered "unlined" surface impoundments under the CCR Rule despite the presence of composite liner systems that were installed with rigorous CQA.

Golder Associates Inc. (Golder) has prepared this report to summarize information establishing that although the existing composite liner systems for Ash Pond 91 and Ash Pond 92 do not strictly meet the current composite liner system specifications in the CCR Rule (as modified by the court decision), they are demonstrably protective of human health and the environment. Determining factors that are discussed in this report include the demonstrated integrity of the geomembrane component of the composite liner systems and a comparison of flux (i.e., the rate of liquid flow) through the composite liner systems for Ash Pond 91 and Ash Pond 92 relative to flux through other liner systems. Some of the key findings are:

- Extensive CQA observation and testing were conducted during installation of the composite liner systems for Ash Pond 91 and Ash Pond 92, providing a solid basis to assess the integrity of the composite liner systems.

- CQA test data from construction of Ash Pond 91 and Ash Pond 92 indicate that the material properties and field seam strengths for the installed 40-mil HDPE geomembrane were comparable to those required of other geomembrane material types and thicknesses that are accepted under the CCR Rule and were superior in most cases.
- Comparisons of flux for various liner systems indicate that the protection of human health and the environment provided by the composite liner systems for Ash Pond 91 and Ash Pond 92 is similar to that provided by the composite liner system that is prescribed under the CCR Rule and vastly superior to that provided by a compacted soil liner.

2.0 EXISTING SITE CONDITIONS

The area surrounding Coal Creek Station is primarily characterized by the presence of mixed glacial deposits. Coal Creek Station and McLean County are situated at the easternmost extent of the Williston Basin, a structural and sedimentary basin (USGS 1999). The region is characterized by the presence of glacial drift, reaching thicknesses of several hundred feet and overlying the Sentinel Butte Member. The Sentinel Butte Member is the highest stratum of the Paleocene Fort Union Formation, overlying the Tongue River, Ludlow, and Cannonball Members (USGS 1999).

The site geology at Coal Creek Station includes unconsolidated surficial deposits of the Coleharbor Formation consisting of stratified and unstratified glacial drift. The near-surface materials consist of silty clay and sandy clay till with interbedded and discontinuous sand lenses (Cooperative Power Association and United Power Association 1989), as shown on the geologic cross-sections through Ash Pond 91 and/or Ash Pond 92 depicted in Appendix A. In general, there is between 5 and 50 feet of low-permeability soil between the bottom of the composite liner systems and the nearest apparent locally continuous sand layer. The thickness of the low-permeability soil layer transitions gradually beneath Ash Pond 91 and Ash Pond 92. The low-permeability soil beneath the site is relatively homogenous.

Permeability tests have been conducted on nine relatively undisturbed (i.e., Shelby tube) samples obtained from relevant depths in boreholes drilled in and around the areas occupied by Ash Pond 91 and Ash Pond 92 to characterize the hydraulic conductivity of the near-surface native soils. The locations of the boreholes from which the samples were obtained are shown in Appendix A. The results of the permeability tests are summarized in Table 1.

Table 1: Permeability Test Results for Native Soils

Year	Borehole	Sample Depth	Soil Description	Hydraulic Conductivity
2014	DP-A	25 feet	Clayey silt, brown	8.6×10^{-8} cm/sec
2014	DP-B	15 feet	Silty clay, trace gravel, dark brown	4.6×10^{-8} cm/sec
2014	DP-C	25 feet	Clayey sand, dark brown, moist	1.2×10^{-7} cm/sec
2014	DP-D	20 feet	Sandy silty clay, dark brown, moist	1.8×10^{-6} cm/sec
2002	SW16-8	76 feet	Clay, some silt, little sand, yellowish-brown	3.9×10^{-7} cm/sec
2001	BH-8	61 feet	Clay, some sand and gravel, dark grayish-brown	8.3×10^{-8} cm/sec
1978	SAP-1	3.5 feet	Silty clay	4.2×10^{-7} cm/sec
1978	SAP-8	12.5 feet	Lean clay	1.5×10^{-7} cm/sec
1978	SAP-10	3.5 feet	Lean clay	1.8×10^{-7} cm/sec
Geometric mean				1.9×10^{-7} cm/sec

The native soils underlying the composite liner systems are characterized by hydraulic conductivity values ranging from 4.6×10^{-8} cm/sec to 1.8×10^{-6} cm/sec, with a geometric mean of 1.9×10^{-7} cm/sec. These near-surface native soils with relatively low hydraulic conductivity provide added protection of groundwater beneath the composite liner systems for Ash Pond 91 and Ash Pond 92.

3.0 EXISTING COMPOSITE LINER SYSTEMS

The liner system design for Ash Pond 91 and Ash Pond 92 is shown in Figure 2. It is a composite liner system design consisting of a minimum two-foot-thick layer of compacted low-permeability soil having a hydraulic conductivity no greater than 1×10^{-7} cm/sec, overlain by a 40-mil HDPE geomembrane.

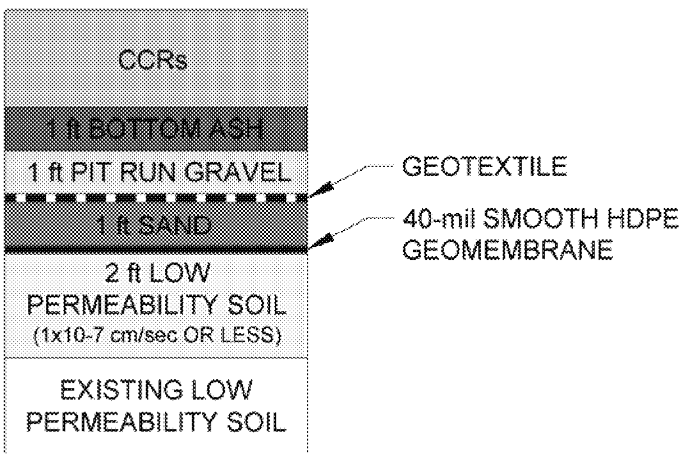

Figure 2: Ash Pond 91 and Ash Pond 92 Liner System Configurations

At the time of construction, composite liner systems were becoming or had recently become the standard of practice for municipal solid waste (MSW) landfills; Subtitle D of the Resource Conservation and Recovery Act (RCRA), which required composite liner systems for MSW landfills, was published in 1991 and took effect in 1993. National minimum standards did not exist for surface impoundments containing CCRs at that time. However, NDDH was implementing a robust set of regulations in North Dakota for protection of human health and the environment. Under NDDH regulations that went into effect in December 1992, surface impoundments were required to have a compacted soil layer at least two feet thick, with the soil having a hydraulic conductivity equal to or less than $1x10^{-7}$ cm/sec. Alternative liner systems were allowed if equivalent protection against leakage could be provided with a different combination of soil layer thickness and hydraulic conductivity or with the use of a geomembrane.

GRE worked with NDDH to develop the composite liner system configurations for Ash Pond 91 and Ash Pond 92, which exceeded the regulatory requirements. As an additional measure, GRE retained third-party engineering firms to conduct rigorous CQA observation and testing of the composite liner systems for Ash Pond 91 and Ash Pond 92 during installation to verify their integrity and conformance with design requirements. These efforts provided a significant amount of documentation that now helps to substantiate the protection of human health and the environment afforded by the composite liner systems for Ash Pond 91 and Ash Pond 92, as described in Sections 3.1 and 3.2.

3.1 Compacted Low-Permeability Soil Layers

CQA data obtained during installation of the composite liner systems included detailed information about the actual hydraulic conductivity of the low-permeability soil layers. Summary tables of falling-head permeability tests conducted on Shelby tube samples taken from the low-permeability soil layer for Ash Pond 91 (Cooperative Power Association 1993) and Ash Pond 92 (Foth & Van Dyke 1990) are included in Appendix B. The permeability testing of the low-permeability soil liners indicates:

- 170 falling-head permeability tests were conducted on Shelby tube samples taken from the low-permeability soil layer for Ash Pond 91. The hydraulic conductivity from these tests ranged from approximately $5x10^{-9}$ cm/sec to $1x10^{-7}$ cm/sec with a geometric mean hydraulic conductivity of $1.7x10^{-8}$ cm/sec.
- 80 falling-head permeability tests were conducted on Shelby tube samples taken from the low-permeability soil layer for Ash Pond 92. The hydraulic conductivity from these tests ranged from approximately $4x10^{-9}$ cm/sec to $1x10^{-7}$ cm/sec with a geometric mean hydraulic conductivity of $4.0x10^{-8}$ cm/sec.

CQA data obtained during installation of the composite liner systems also included detailed information about the actual thickness of the low-permeability soil layers:

- Golder evaluated the actual thickness of the low-permeability soil layer for Ash Pond 91 by comparing topographic surveys conducted immediately before and immediately after installation of the low-permeability soil layer (Interstate Engineering 1994). The thickness of the low-permeability soil layer ranged between approximately 2 and 4.5 feet with an average thickness of 2.4 feet.
- The actual thickness of the low-permeability soil layer for Ash Pond 92 was measured by taking survey shots of the subgrade and the top of the low-permeability soil layer in 61 locations (on a grid spacing of 200 feet or less) as part of the CQA procedures during construction (Foth & Van Dyke 1990). The thickness of the low-permeability soil layer ranged between approximately 2 and 3 feet with an average thickness of 2.3 feet.

The information pertaining to the actual hydraulic conductivity and thickness of the low-permeability soil layers is used in Section 5.0 to help compare the expected effectiveness of the composite liner systems for Ash Pond 91 and Ash Pond 92, in terms of limiting flux, against the expected effectiveness of other liner systems.

3.2 Geomembrane

CQA data obtained during installation of the composite liner systems included detailed information about the strength of the 40-mil HDPE geomembrane materials. Summary tables of geomembrane properties from manufacturer quality control certificates, laboratory conformance testing, and laboratory seam strength testing of field welded seams are included in Appendix C for Ash Pond 91 (Cooperative Power Association 1993) and Ash Pond 92 (Foth & Van Dyke 1990). The tests were performed on geomembrane samples either taken from rolls that were delivered to the site or on destructive geomembrane seam samples taken during installation. All tests (manufacturer quality control reports, laboratory conformance testing, and laboratory seam strength testing of field-welded seams) met or exceeded the requirements of the geomembrane liner specifications. The average results from these tests are shown in Table 2 and Table 3.

Table 2: Geomembrane Roll Quality Control and Conformance Testing Results

Property	Units	Test Method	Ash Pond 91 Average	Ash Pond 92 Average
Thickness	mils	ASTM D1593	44	42
Yield Strength	pounds per inch	ASTM D638	121	98
Break Strength	pounds per inch	ASTM D638	220	195
Tear Resistance	pounds	ASTM D1004	37	34
Puncture Resistance	pounds	FTMS 101C 2065	86	64

Table 3: Geomembrane Field Seam Destructive Testing Results

Property	Units	Test Method	Ash Pond 91 Average	Ash Pond 92 Average
Seam Shear Strength	pounds per inch	ASTM D638	127	106
Seam Peel Strength	pounds per inch	ASTM D638	86	84

The information pertaining to the actual strength of the 40-mil HDPE geomembrane materials is used in Section 4.0 to help assess the adequacy of 40-mil HDPE geomembrane to withstand the anticipated stresses on the composite liner systems for Ash Pond 91 and Ash Pond 92.

4.0 GEOMEMBRANE INTEGRITY

Golder investigated the rationale behind the 60-mil thickness requirement for HDPE geomembrane in 40 CFR 257.71(a)(1)(ii). This requirement mirrors a similar requirement for liner systems beneath MSW landfills found in RCRA Subtitle D [40 CFR 258.40(2)(b)]:

> "…composite liner means a system consisting of two components; the upper component must consist of a minimum 30-mil flexible membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than $1x10^{-7}$ cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60-mil thick."

Golder infers that the regulatory language in the CCR Rule is derived from the regulatory language in RCRA Subtitle D, which was developed in the late 1980s and early 1990s. After a search into documents from that period, the most pertinent rationale we have been able to identify for the 60-mil thickness requirement for HDPE is summarized in the following excerpt from the Solid Waste Disposal Facility Criteria Technical Manual (U.S. EPA 1993):

> "The polymeric materials used most frequently as geomembranes are HDPE, PVC [polyvinyl chloride], CSPE [chlorosulfonated polyethylene], and CPE [chlorinated polyethylene]. The thicknesses of geomembranes range from 20 to 120 mil (1 mil = 0.001 inch) (U.S. EPA 1983 and U.S. EPA 1988). The recommended minimum thickness for all geomembranes is 30 mil, with the exception of HDPE, which must be at least 60 mil to allow for proper seam welding."

There are no examples or references cited in the document or in the preamble to RCRA Subtitle D providing the basis for the statement that HDPE geomembrane must be at least 60 mils thick to allow for proper seam welding. HDPE geomembranes with 40-mil thickness have been routinely and successfully used in impoundment liner systems and landfill cover systems in the intervening years. The demonstrated integrity of the geomembrane materials and field seams produced for the Ash Pond 91 and Ash Pond 92 composite liner systems is described in Sections 4.1, 4.2, and 4.3.

4.1 Minimum Geomembrane Properties for Survivability

Koerner (2012) provides guidance for the selection of minimum geomembrane properties for installation survivability, which refers to the ability of the geomembrane to survive the packaging, transportation, handling, unloading, storage, and installation processes. More severe installation conditions tend to require a higher degree of survivability; the required degree of survivability for the Ash Pond 91 and Ash Pond 92 composite liner systems would be categorized as Medium to High due to the machine-graded subgrade and relatively high loads. The minimum properties for installation survivability are summarized in Table 4 and compared against actual average properties for geomembrane materials used in the composite liner systems for Ash Pond 91 and Ash Pond 92.

Table 4: Comparison of Geomembrane Properties for Installation Survivability

Property	Required Degree of Installation Survivability				Ash Pond 91	Ash Pond 92
	Low[1]	Medium[2]	High[3]	Very High[4]		
Thickness	25 mil (ASTM D1593)	30 mil (ASTM D1593)	35 mil (ASTM D1593)	40 mil (ASTM D1593)	44 mil (ASTM D1593)	42 mil (ASTM D1593)
Tensile Strength	52 pounds per inch (ASTM D882)	66 pounds per inch (ASTM D882)	81 pounds per inch (ASTM D882)	96 pounds per inch (ASTM D882)	121 pounds per inch (ASTM D638)	98 pounds per inch (ASTM D638)
Tear Resistance	7 pounds (ASTM D1004)	10 pounds (ASTM D1004)	15 pounds (ASTM D1004)	20 pounds (ASTM D1004)	37 pounds (ASTM D1004)	34 pounds (ASTM D1004)
Puncture Resistance	25 pounds (ASTM D4833)	32 pounds (ASTM D4833)	38 pounds (ASTM D4833)	45 pounds (ASTM D4833)	86 pounds (99 to 116 pounds [5]) (FTMS 101C 2065)	64 pounds (73 to 86 pounds [5]) (FTMS 101C 2065)

1. "Low" refers to careful hand placement on very uniform well-graded subgrade with light loads of a static nature, typical of vapor barriers beneath building floor slabs (Koerner 2012).
2. "Medium" refers to hand or machine placement on smooth, machine-graded subgrade with medium load, typical of canal liners (Koerner 2012).
3. "High" refers to hand or machine placement on machine-graded subgrade of poor texture with high loads, typical of landfill liners and covers (Koerner 2012).
4. "Very High" refers to hand or machine placement on machine-graded subgrade of very poor texture with high loads, typical of liners for heap leach pads and construction/demolition wastes (Koerner 2012).
5. Values determined from FTMS 101C 2065 are typically 15 to 35 percent lower than values determined from ASTM D4833 (Sheirs 2009).

Based on the information presented in Table 4, the geomembrane components of the composite liner systems for Ash Pond 91 and Ash Pond 92 exceed even the Very High survivability requirements, which would be applicable to more severe installation conditions than those that existed during construction of Ash Pond 91 and Ash Pond 92. This provides confidence that the geomembrane components were delivered, handled, and installed without damage.

4.2 Geomembrane Material Properties

The material strength properties for the geomembrane used in the composite liner systems for Ash Pond 91 and Ash Pond 92 are compared with the required material strength properties (based on current specifications) for various geomembranes types and thicknesses that are acceptable under the CCR Rule in Table 5.

Table 5: Comparison of Geomembrane Material Properties

Material	Yield Strength	Yield Elongation	Break Strength	Break Elongation	Tear Resistance	Puncture Resistance
	ASTM D638	ASTM D638	ASTM D638	ASTM D638	ASTM D1004	FTMS 101C 2065
Ash Pond 91 40-mil HDPE	121 pounds per inch (actual)	18% (actual)	220 pounds per inch (actual)	818% (actual)	37 pounds (actual)	86 pounds (actual) (99 to 116 pounds [1])
Ash Pond 92 40-mil HDPE	98 pounds per inch (actual)	23% (actual)	195 pounds per inch (actual)	857% (actual)	34 pounds (actual)	64 pounds (actual) (73 to 86 pounds [1])
Material	ASTM D6693	ASTM D6693	ASTM D6693	ASTM D6693	ASTM D1004	ASTM D4833
40-mil HDPE GRI GM13 (GSI 2016)	84 pounds per inch (minimum)	12% (minimum)	152 pounds per inch (minimum)	700% (minimum)	28 pounds (minimum)	72 pounds (minimum)
60-mil HDPE (smooth) GRI GM13 (GSI 2016)	126 pounds per inch (minimum)	12% (minimum)	228 pounds per inch (minimum)	700% (minimum)	42 pounds (minimum)	108 pounds (minimum)
60-mil HDPE (textured) GRI GM13 (GSI 2016)	126 pounds per inch (minimum)	12% (minimum)	90 pounds per inch (minimum)	100% (minimum)	42 pounds (minimum)	90 pounds (minimum)
30-mil LLDPE GRI GM17 (GSI 2015a)	None	None	114 pounds per inch	800% (minimum)	16 pounds (minimum)	42 pounds (minimum)
30-mil fPP GRI GM18 (GSI 2015b)	None	None	60 pounds per inch (minimum)	700% (minimum)	10 pounds (minimum)	25 pounds (minimum)
Material	ASTM D882	ASTM D882	ASTM D882	ASTM D882	ASTM D1004	None
30-mil PVC ASTM D7176 (ASTM 2006)	None	None	73 pounds per inch (minimum)	380% (minimum)	8 pounds (minimum)	None

1. Actual average value increased by 15 to 35 percent for comparison against puncture resistance determined from ASTM D4833 (Sheirs 2009).

Based on the comparisons shown in Table 5, in all cases, the actual geomembrane property averages for Ash Pond 91 and Ash Pond 92 exceeded the required values for 30-mil LLDPE (linear low density polyethylene), 30-mil fPP (flexible polypropylene), and 30-mil PVC, all of which are adequate to serve as the upper component in a composite liner system under 40 CFR 257.71(a)(1)(ii). Additionally, the actual geomembrane property averages for Ash Pond 91 and Ash Pond 92 exceeded the requirements for 40-mil HDPE geomembrane and are comparable to the requirements for 60-mil HDPE geomembrane (smooth and textured). Therefore, the yield stress, yield elongation, break strength, break elongation, tear resistance, and puncture resistance for the 40-mil geomembrane materials used for Ash Pond 91 and Ash Pond 92 are superior to those required of materials that could be used in composite liner systems under the CCR Rule.

Design calculations can be used to evaluate the strength of a geomembrane with a given thickness and material composition against the range of stresses that could be imposed. Koerner (2012) presents an equation that can be used to determine the minimum geomembrane thickness, t, that is needed to resist the estimated tensile forces introduced by subsurface deformation that may be experienced during the geomembrane's service lifetime. The inputs to the equation are as follows:

- Normal stress on the composite liner system, σ_n, which results from the weight of the CCRs contained in the surface impoundment. For the most conservative application of the equation, σ_n is the product of the maximum height of the CCR deposit, H, and the unit weight of the CCRs, γ.
- Distance of mobilized geomembrane deformation, X. A value of 2 inches is appropriate for relatively high normal stress conditions, like in the Ash Pond 91 and Ash Pond 92 composite liner systems (Koerner 2012).
- Angle of shearing resistance between the geomembrane and the material overlying the geomembrane, δ_U.
- Angle of shearing resistance between the geomembrane and the material underlying the geomembrane, δ_L.
- Allowable shear stress for geomembrane, σ_{allow}. For purposes of this calculation, allowable shear stress is taken as the average yield stress (refer to Table 5) divided by the geomembrane thickness.
- Deformation angle mobilizing the tension in the geomembrane, β.

The equation for minimum geomembrane thickness is as follows:

$$t = \frac{\sigma_n X (tan\ \delta_U + tan\ \delta_L)}{\sigma_{allow} (cos\ \beta - sin\ \beta\ tan\ \delta_L)}$$

Based on consolidation analyses completed by Golder along Cross Sections B, D, and E through Ash Pond 91 and/or Ash Pond 92 (refer to Appendix A), the maximum strain that the geomembrane component of the composite liner systems would be expected to experience is less than 1 percent. The relatively homogeneous near-surface soils, gradual changes in stratum thickness and impoundment geometry, and slow rate of CCR loading contribute to these relatively low expected strain levels. As a result, the deformation angle mobilizing the tension in the geomembrane, β, is estimated to be no greater than 5 degrees.

The angle of shearing resistance between the geomembrane and the sand overlying the geomembrane, δ_U, is estimated as 17 degrees based on a best-fit of 128 interface friction tests between smooth HDPE and granular soil reported by the Geosynthetics Research Institute (GRI 2005). The angle of shearing resistance between the geomembrane and the clay underlying the geomembrane, δ_L, has been evaluated through interface friction testing of site-specific materials and was determined to be 7 degrees (Great River Energy 2015).

For the conservative case with the highest anticipated normal stresses at Ash Pond 91 (H = 110 feet and γ = 100 pounds per cubic foot), the calculated minimum geomembrane thickness for Ash Pond 91 is 0.022 inches (22 mils). The existing 40-mil HDPE geomembrane is sufficiently thick to withstand the anticipated stresses on the composite liner system.

For the conservative case with the highest anticipated normal stresses at Ash Pond 92 (H= 120 feet and γ = 100 pounds per cubic foot), the calculated minimum geomembrane thickness for Ash Pond 92 is 0.030 inches (30 mils). The existing 40-mil HDPE geomembrane is sufficiently thick to withstand the anticipated stresses on the composite liner system.

4.3 Field Seaming

Extensive CQA observation and testing were conducted on the field seams between 40-mil geomembrane panels for the Ash Pond 91 and Ash Pond 92 composite liner systems during installation. The results of destructive testing on seam samples taken during installation indicate that the seam strengths met the project requirements. Table 6 compares the destructive test results for Ash Pond 91 and Ash Pond 92 against industry-accepted seam strength requirements for 40-mil HDPE and for various geomembrane materials and thicknesses that are adequate for use as the upper component of a composite liner system under the CCR Rule.

Table 6: Comparison of Geomembrane Seam Strengths

Material	Test Method [1]	Shear Strength	Peel Strength
Ash Pond 91 40-mil HDPE	ASTM D638	127 pounds per inch (actual)	86 pounds per inch (actual)
Ash Pond 92 40-mil HDPE	ASTM D638	106 pounds per inch (actual)	84 pounds per inch (actual)
40-mil HDPE GRI GM19a (GSI 2017)	ASTM D6392	80 pounds per inch (minimum)	60 pounds per inch (minimum)
60-mil HDPE GRI GM19a (GSI 2017)	ASTM D6392	120 pounds per inch (minimum)	91 pounds per inch (minimum)
30-mil LLDPE GRI GM19a (GSI 2017)	ASTM D6392	45 pounds per inch (minimum)	38 pounds per inch (minimum)
30-mil fPP GRI GM19a (GSI 2017)	ASTM D6392	25 pounds per inch (minimum)	20 pounds per inch (minimum)
30-mil PVC ASTM D7176 (ASTM 2006)	ASTM D882	58 pounds per inch (minimum)	15 pounds per inch (minimum)

1. ASTM D638 is applicable to tensile testing of various plastics and was commonly used for destructive testing of geomembrane seams when Ash Pond 91 and Ash Pond 92 were constructed. Test methods like ASTM D6392 have since been developed specifically for testing geomembrane seams. The test procedures and the strengths measured by the two test methods are comparable.

Based on the comparisons shown in Table 6, the actual seam strength averages exceeded the required values for 30-mil LLDPE, 30-mil fPP, and 30-mil PVC, all of which are adequate to serve as the upper component in a composite liner system under 40 CFR 257.71(a)(1)(ii). Additionally, the actual seam shear strength and peel strength averages for Ash Pond 91 and Ash Pond 92 exceeded the requirements for 40-mil HDPE geomembrane and are comparable to the strength requirements for 60-mil HDPE geomembrane.

In 2005 and 2016, the composite liner systems for Ash Pond 91 and Ash Pond 92 were exposed in some locations to extend the lined area, and the 40-mil HDPE geomembrane component was joined by field seaming to new 60-mil HDPE or LLDPE geomembrane. CQA observations indicated excellent longevity of the 40-mil HDPE geomembrane, and destructive samples of the resulting field seams were obtained and tested to verify that project requirements were being met. The test results are summarized in Table 7.

Table 7: Destructive Test Results for 2005 and 2016 Field Seams

Specimen Identifier, Year, and Location	Shear Strength (ASTM D6392, Average of 5 Tests)	Shear Strength Requirement GRI GM-19a 40-mil HDPE	Upper Peel Strength (ASTM D6392, Average of 5 Tests)	Lower Peel Strength (ASTM D6392, Average of 5 Tests)	Peel Strength Requirement GRI GM-19a 40-mil HDPE
DF26 (2005) Ash Pond 92	117 pounds per inch	80 pounds per inch (minimum)	89 pounds per inch	97 pounds per inch	60 pounds per inch (minimum)
DF48 (2005) Ash Pond 92	130 pounds per inch	80 pounds per inch (minimum)	89 pounds per inch	89 pounds per inch	60 pounds per inch (minimum)
DF64 (2005) Ash Pond 92	120 pounds per inch	80 pounds per inch (minimum)	103 pounds per inch	103 pounds per inch	60 pounds per inch (minimum)
DF86 (2005) Ash Pond 92	110 pounds per inch	80 pounds per inch (minimum)	96 pounds per inch	96 pounds per inch	60 pounds per inch (minimum)
DS32 (2016) Ash Pond 92	124 pounds per inch	80 pounds per inch (minimum)	94 pounds per inch	94 pounds per inch	60 pounds per inch (minimum)
DS37 (2016) Ash Pond 92	120 pounds per inch	80 pounds per inch (minimum)	106 pounds per inch	94 pounds per inch	60 pounds per inch (minimum)
DS-39 (2016) Ash Pond 92	136 pounds per inch	80 pounds per inch (minimum)	115 pounds per inch	95 pounds per inch	60 pounds per inch (minimum)
DS10 (2016) Ash Pond 91	115 pounds per inch	80 pounds per inch (minimum)	103 pounds per inch	108 pounds per inch	60 pounds per inch (minimum)
DS15 (2016) Ash Pond 91	114 pounds per inch	80 pounds per inch (minimum)	102 pounds per inch	94 pounds per inch	60 pounds per inch (minimum)
DS35 (2016) Ash Pond 91	128 pounds per inch	80 pounds per inch (minimum)	101 pounds per inch	102 pounds per inch	60 pounds per inch (minimum)
DS36 (2016) Ash Pond 91	145 pounds per inch	80 pounds per inch (minimum)	131 pounds per inch	124 pounds per inch	60 pounds per inch (minimum)

The CQA observations and the test results summarized in Table 7 confirm the integrity and longevity of the 40-mil HDPE geomembrane materials and the capability to produce quality welded seams, even 20 years or more after the 40-mil geomembrane was originally installed. In fact, the shear strengths and peel strengths are comparable to, and in most cases higher than, those required for 60-mil HDPE field seams under current industry standards.

Based on the information presented in this section regarding field seaming for the Ash Pond 91 and Ash Pond 92 composite liner systems, concerns about producing quality welded seams using 40-mil HDPE geomembrane appear to be unfounded, at least in this case.

5.0 LINER SYSTEM FLUX

The rate of liquid flow (flux) through a liner system is one of the key factors used in determining the level of risk to human health and the environment associated with a surface impoundment. In its decision, the United States Court of Appeals for the District of Columbia Circuit noted that:

> The record evidence shows that an impoundment with composite lining, which the Rule requires of all new impoundments, has a 0.1 per cent chance of contaminating groundwater at drinking-water wells a mile distant from the impoundment perimeter over the course of a 100-year period.

and:

> Clay-lined surface impoundments have a 9.1 per cent chance of causing groundwater contamination at a drinking water wells at a one-mile distance from the impoundment perimeter.

The dissimilar level of risk presented by clay-lined surface impoundments and composite-lined surface impoundments (nearly two orders of magnitude different) was a key reason the United States Court of Appeals for the District of Columbia Circuit vacated the portion of the CCR Rule that had allowed for a liner system consisting solely of two feet of compacted soil.

Golder performed a set of calculations to estimate flux through the composite liner systems for Ash Pond 91 and Ash Pond 92 for comparison against flux estimates for a compacted soil liner like the one represented by the liner system design criteria in 40 CFR 257.71(a)(1)(i), and for a composite liner system like the one represented by the liner system design criteria in 40 CFR 257.71(a)(1)(ii). The purpose of conducting this comparison was to evaluate whether the composite liner systems for Ash Pond 91 and Ash Pond 92 present a level of risk that is more like that of a clay liner, which was unacceptable to the United States Court of Appeals for the District of Columbia Circuit, or more like that of a composite liner system that is accepted under the CCR Rule, which was satisfactory to the United States Court of Appeals for the District of Columbia Circuit.

The CCR Rule provides an equation based on Darcy's Law to compute flux per unit area, q, through a compacted soil layer [40 CFR 257.70(c)(2)]. The inputs to the equation are as follows:

- Hydraulic head on the top of the compacted soil layer, h.
- Thickness of the compacted soil layer, t_s.
- Saturated vertical hydraulic conductivity of the compacted soil layer, k_s.

The equation is as follows:

$$q = k_s\left(\frac{h}{t_s} + 1\right)$$

Giroud (1997) presents an equation that can be used to estimate the flux, Q, through a circular[2] geomembrane defect in a composite liner system consisting of a geomembrane as the upper component and a low-permeability soil layer as the lower component, like the composite liner systems for Ash Pond 91 and Ash Pond 92. The mechanism of liquid migration considered is advective flow through a defect in the geomembrane. The inputs to the equations are as follows:

- Contact quality factor, C_{qo}, which relates to the intimacy of contact between the geomembrane and the underlying low-permeability soil layer. This factor defines the distance to which liquid is assumed to migrate laterally between the geomembrane and the low-permeability soil layer after it has passed through a geomembrane defect. Good contact is characterized by a geomembrane installed with few wrinkles on a well-compacted and smooth soil surface and is reasonably assumed when a rigorous CQA program is carried out. Poor contact is characterized by a geomembrane installed with more wrinkles and/or placed on a soil surface that is not well compacted or is not smooth.
- Hydraulic head on the top of the composite liner system, h.
- Thickness of the low-permeability soil layer beneath the geomembrane, t_s.
- Diameter of the geomembrane defect, d.
- Saturated vertical hydraulic conductivity of the low-permeability soil layer beneath the geomembrane, k_s.

The equation is as follows:

$$Q = 0.976\, C_{qo} \left[1 + 0.1\left(\frac{h}{t_s}\right)^{0.95}\right] d^{0.2}\, h^{0.9}\, {k_s}^{0.74}$$

Flux, Q, can also be multiplied by the number of geomembrane defects per unit area, N, to obtain the flux per unit area, q. The following observations regarding the use of this equation for comparative purposes are noteworthy:

- The relationship between calculated flux and assumed contact quality factor, C_{qo}, is linear. Thus, a change in the value assumed for contact quality factor would affect each computation proportionately.
- Similarly, a change in the assumed defect diameter would affect each computation proportionately.
- Geomembrane thickness is not an input to the equation because the theoretical influence of geomembrane thickness is inconsequential.

Golder performed a set of calculations using both equations to compare flux estimates through four different liner systems:

1. Compacted Soil Liner – The compacted soil liner that is represented by the liner system design criteria in 40 CFR 257.71(a)(1)(i), which consists of a two-foot-thick layer of soil having a saturated vertical hydraulic conductivity equal to $1\text{x}10^{-7}$ cm/sec.
2. Prescriptive Composite Liner System – The composite liner system that is represented by the liner system design criteria in 40 CFR 257.71(a)(1)(ii), which consists of a geomembrane (60-mil HDPE or

[2] Equations for other defect shapes, such as square and rectangular, are comparable and not presented for simplicity.

other accepted type and thickness) as the upper component and a two-foot-thick layer of soil having a saturated vertical hydraulic conductivity equal to 1×10^{-7} cm/sec as the lower component.

3. Ash Pond 91 Composite Liner – A composite liner system that consists of a 40-mil HDPE geomembrane as the upper component and a 2.4-foot-thick low-permeability soil layer having a saturated vertical hydraulic conductivity of 1.7×10^{-8} cm/sec (the geometric mean saturated vertical hydraulic conductivity from CQA testing on the Ash Pond 91 low-permeability soil layer).
4. Ash Pond 92 Composite Liner – A composite liner system that consists of a 40-mil HDPE geomembrane as the upper component and a 2.3-foot-thick low-permeability soil layer having a saturated vertical hydraulic conductivity of 4.0×10^{-8} cm/sec (the geometric mean saturated vertical hydraulic conductivity from CQA testing on the Ash Pond 92 low-permeability soil layer).

Flux estimates were calculated for a range of hydraulic head from 1 to 3 feet. For the composite liner systems, flux estimates were calculated with assumptions for geomembrane defect size and defect density that are consistent with those made by the U.S. EPA in the Industrial Waste Management Evaluation Model (U.S. EPA 2002). In their model, the U.S. EPA assumed a uniform geomembrane defect size of 6 square millimeters (mm^2), which was the middle range of defect sizes reported. The U.S. EPA also developed a cumulative frequency distribution (CFD) of defect density for composite liner systems based on defect density data from 26 sites (composite liner systems installed with formal CQA programs). The defect density found at these sites ranged from 0 to 5 defects per acre, with a median defect density of less than 1 defect per acre (0.4 defects per acre). For Golder's analysis, geomembrane defect densities of 1 per acre and 5 per acre were modeled to provide an estimate of composite liner system flux at the higher end of defect density (70th to 100th percentile range from the U.S. EPA's CFD). The composite liner systems for Ash Pond 91 and Ash Pond 92 were subjected to rigorous CQA programs, so C_{qo} was assumed to be equal to 0.21 (indicative of good contact, per Giroud 1997) for these comparisons. For consistency, the same assumption was made for the Prescriptive Composite Liner System.

The calculations were not performed to estimate actual flux through the Ash Pond 91 and 92 composite liner systems. Rather, the calculations were performed to provide side-by-side comparisons of flux through various liner systems, as computed using a consistent set of assumptions, and identify whether the Ash Pond 91 and Ash Pond 92 likely present a level of risk that is more like that of a clay liner or more like that of a composite liner system that is accepted under the CCR Rule. The results are summarized in Table 8 and presented graphically in Figure 3.

Table 8: Relative Liner System Flux Comparisons

Liner System	Geomembrane Defect Density	Liner System Flux		
		Hydraulic Head = 1 foot	Hydraulic Head = 2 feet	Hydraulic Head = 3 feet
Compacted Soil Liner	Not applicable	139 gallons per acre per day	185 gallons per acre per day	231 gallons per acre per day
Prescriptive Composite Liner System	1 per acre	0.1 gallons per acre per day	0.2 gallons per acre per day	0.3 gallons per acre per day
	5 per acre	0.6 gallons per acre per day	1.1 gallons per acre per day	1.7 gallons per acre per day
Ash Pond 91 Composite Liner System	1 per acre	0.0 gallons per acre per day	0.1 gallons per acre per day	0.1 gallons per acre per day
	5 per acre	0.2 gallons per acre per day	0.3 gallons per acre per day	0.4 gallons per acre per day
Ash Pond 92 Composite Liner System	1 per acre	0.1 gallons per acre per day	0.1 gallons per acre per day	0.2 gallons per acre per day
	5 per acre	0.3 gallons per acre per day	0.6 gallons per acre per day	0.8 gallons per acre per day

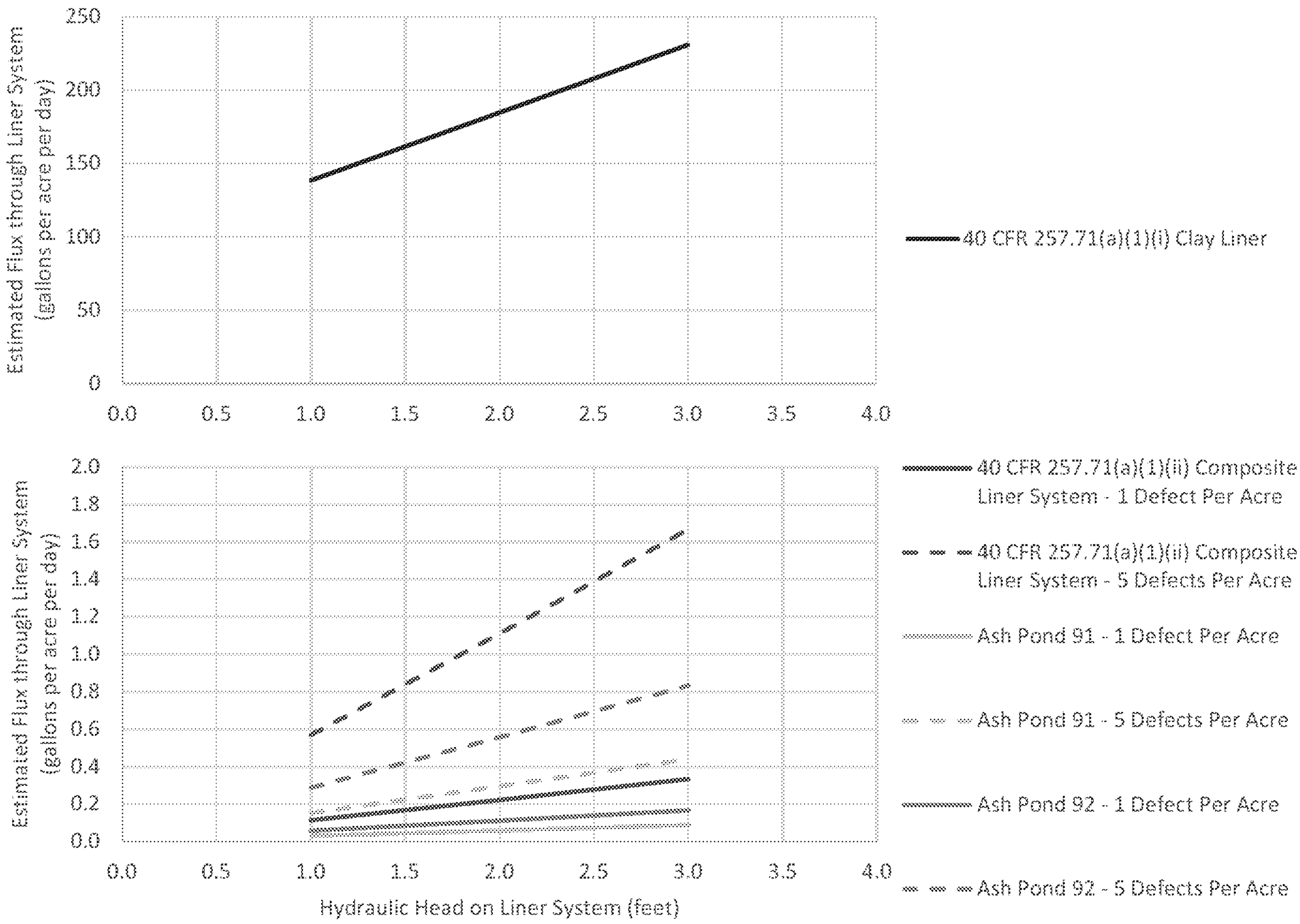

Figure 3: Relative Liner System Flux Comparisons

This comparison indicates that the Ash Pond 91 and Ash Pond 92 composite liner systems present a level of risk that is similar to that of the composite liner system that is accepted under the CCR Rule, which was satisfactory to the United States Court of Appeals for the District of Columbia Circuit. The flux for the Ash Pond 91 and Ash Pond 92 composite liner systems is several orders of magnitude lower than that of a compacted soil liner across a reasonable range of defect densities.

6.0 CONCLUSION

The recent court decision issued by the United States Court of Appeals for the District of Columbia Circuit (No. 15-1219, decided August 21, 2018) vacating the portion of the CCR Rule that provided the basis for Ash Pond 91 and Ash Pond 92 to be considered “lined” impoundments under the CCR Rule has prompted preparation of this report to establish the level to which the existing Ash Pond 91 and Ash Pond 92 composite liner systems are protective of human health and the environment. Key aspects of the liner system that have been evaluated include flux through the composite liner system for Ash Pond 91 and Ash Pond 92 as compared with flux through other liner systems and the integrity of the 40-mil HDPE geomembrane component, including field seams between panels. Conclusions from these evaluations include the following:

- Extensive CQA observation and testing were conducted during installation of the composite liner systems for Ash Pond 91 and Ash Pond 92, providing a solid basis to assess the integrity of the composite liner systems.
- The quality of installation for soil and geomembrane components of the Ash Pond 91 and Ash Pond 92 composite liner systems is substantiated by a considerable amount of CQA test data, which show that materials consistently met or exceeded the specified construction requirements. In particular, the actual hydraulic conductivity and actual thickness of the low-permeability soil layers surpassed the design and regulatory requirements, as did the actual integrity-related properties for the geomembrane materials.
- CQA test data from construction of Ash Pond 91 and Ash Pond 92 indicate that the shear and peel strengths of seams between panels of the installed 40-mil HDPE geomembrane were comparable to those required of other geomembrane material types and thicknesses that are accepted under the CCR Rule and were superior in most cases. Subsequent tests on seams made in 2005 and 2016 to tie into these existing liner systems indicated that the shear and peel strength of the 40-mil HDPE geomembrane continued to exceed required strengths, even after 20 years or more in service, and in most cases were higher than those required for 60-mil HDPE field seams under current industry standards.
- CQA test data from construction of Ash Pond 91 and Ash Pond 92 indicate that the strength, tear, and puncture properties of the installed 40-mil HDPE geomembrane material were comparable to those required of other geomembrane material types and thicknesses that are accepted under the CCR Rule, and were superior in most cases.
- Comparisons of liner system flux indicate that the Ash Pond 91 and Ash Pond 92 composite liner systems present a level of risk that is similar to that of the composite liner system that is accepted under the CCR Rule, which was satisfactory to the United States Court of Appeals for the District of Columbia Circuit. The flux for the Ash Pond 91 and Ash Pond 92 composite liner systems is several orders of magnitude lower that of a compacted soil liner.
- The native soils underlying the composite liner systems consist primarily of silty clay and sandy clay till. In situ permeability testing conducted in and around Ash Pond 91 and Ash Pond 92 has yielded hydraulic conductivity values ranging from 4.6×10^{-8} cm/sec to 1.8×10^{-6} cm/sec, with a geometric mean of 1.9×10^{-7} cm/sec. This relatively low hydraulic conductivity in near-surface native soils provides added protection of human health and the environment.
- Industry-accepted stress-strain calculations for geomembrane design indicate that the selected thickness of 40 mils is sufficient for the geomembrane component in the composite liner systems for Ash Pond 91 and Ash Pond 92.

Golder concludes, based on the supporting information provided in this report, that the existing composite liner systems for Ash Pond 91 and Ash Pond 92 are appropriately protective of human health and the environment.

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Signature Page

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Associate/Senior Consultant

JEO/TJS/ds

APPENDIX A

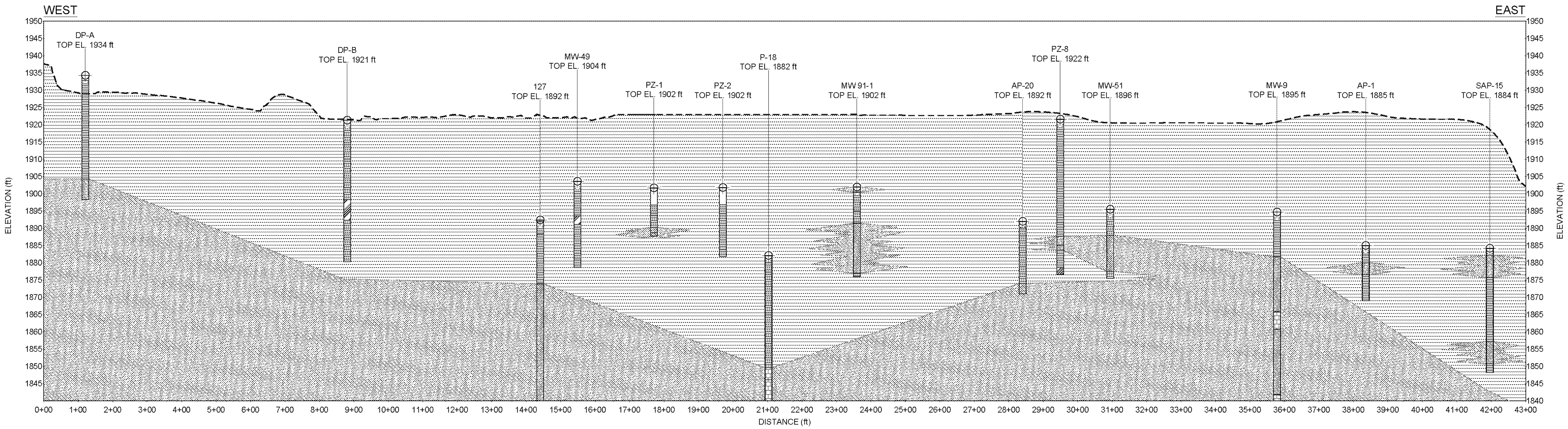
Geologic Cross-Sections

GOLDER

THE SITE AERIAL IMAGE IS FROM THE UNITED STATES DEPARTMENT OF AGRICULTURE NATIONAL AGRICULTURE IMAGERY PROGRAM AND WAS ACQUIRED IN 2017. THE LOCATION OF THE AERIAL IMAGE IS APPROXIMATE.

SITE OVERVIEW
LOCATION OF GEOLOGIC SECTIONS

FIGURE A1



GEOLOGIC LEGEND

LOW PERMEABILITY MATERIALS — CLAY, CLAY LINER, SILT, SILTSTONE/ SHALE

HIGH PERMEABILITY MATERIALS — SAND, SANDSTONE

OTHER — COAL, ASH/CCR

CROSS SECTION LEGEND

EXISTING GROUND (BASED ON SURVEY)

APPROXIMATE EXISTING GROUND (BASED ON SITE OBSERVATIONS AND AERIAL IMAGERY)

APPROXIMATE MATERIAL BOUNDARIES

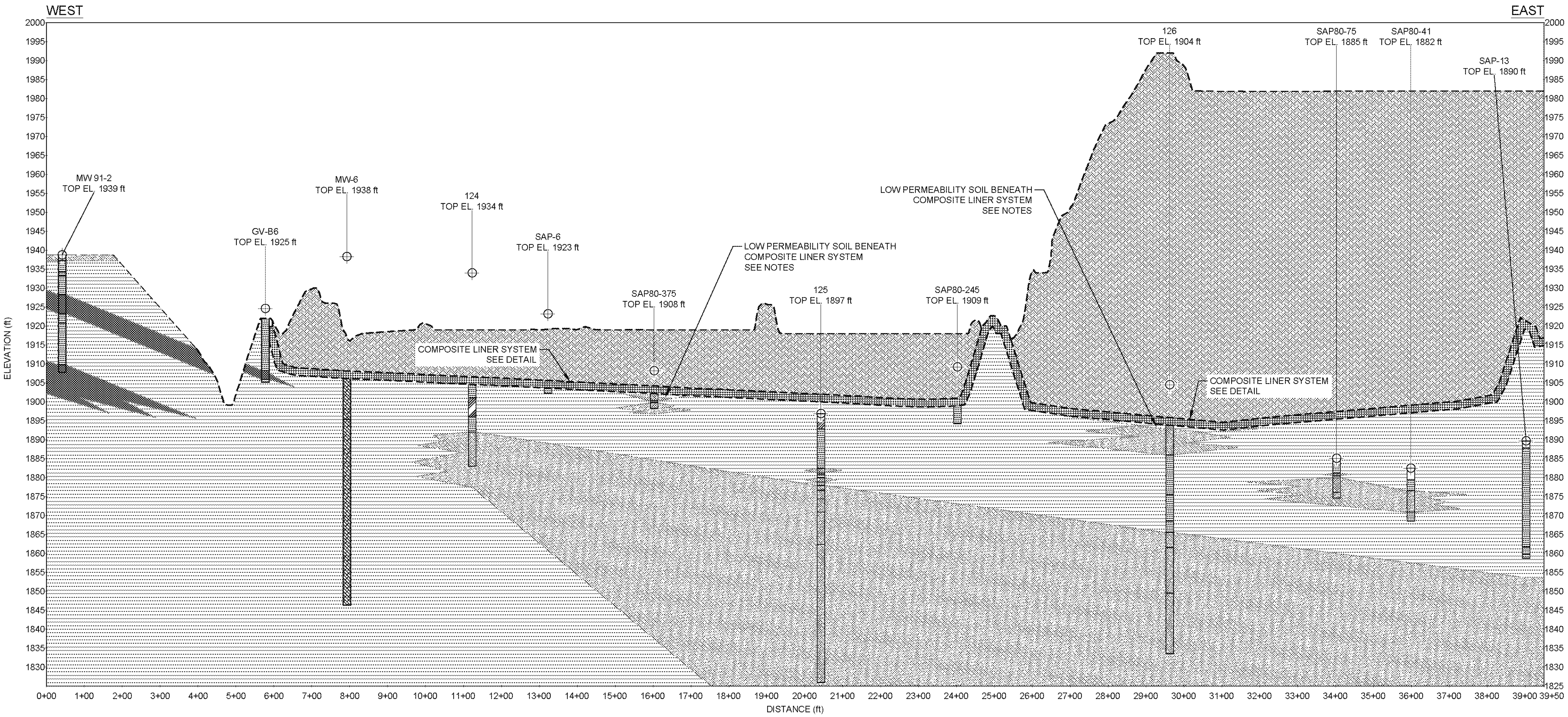
NOTES

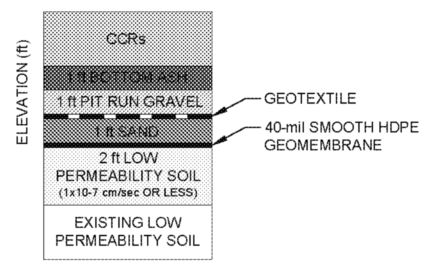
1. BORING INFORMATION IS BASED ON INFORMATION PROVIDED BY GREAT RIVER ENERGY. THE ELEVATIONS OF BORINGS ARE APPROXIMATE AND BORING INFORMATION HAS BEEN PROJECTED TO APPLICABLE SECTIONS.
2. HISTORIC BORINGS MAY BE TRUNCATED AT THE TOP OF LINER OR CURRENT EXISTING GROUND SURFACE GRADES DUE TO CHANGES IN SITE GEOMETRY SINCE BORINGS WERE COMPLETED. BORINGS WITHIN LINED FACILITY BOUNDARIES ARE HISTORIC AND WERE COMPLETED PRIOR TO COMPOSITE LINER CONSTRUCTION.
3. MATERIAL BOUNDARIES WERE DRAWN BASED ON BORING INFORMATION AND SITE OBSERVATIONS AND ARE SHOWN FOR INFORMATION ONLY.
4. INFORMATION FROM CONSTRUCTION QUALITY ASSURANCE DOCUMENTATION INDICATES THAT SOME LOCATIONS BELOW THE DESIGN SUBGRADE OF ASH POND 91 AND ASH POND 92 (INCLUDING SAND LENSES) WERE OVER-EXCAVATED AND BACKFILLED WITH LOW PERMEABILITY SOIL PRIOR TO CONSTRUCTION OF THE COMPOSITE LINER SYSTEM.
5. LOW PERMEABILITY SOILS ARE GENERALLY EXPECTED TO HAVE SATURATED HYDRAULIC CONDUCTIVITIES LESS THAN $1x10^{-6}$ cm/sec AND HIGH PERMEABILITY SOILS ARE GENERALLY EXPECTED TO HAVE SATURATED HYDRAULIC CONDUCTIVITY GREATER THAN $1x10^{-5}$ cm/sec.
6. EXISTING GROUND, LINER GRADES, AND ASH/CCR GRADES ARE APPROXIMATE.

GOLDER

CROSS SECTION A
NORTH SIDE - ASH POND 91/92

FIGURE A2





1 COMPOSITE LINER SYSTEM

GEOLOGIC LEGEND

LOW PERMEABILITY MATERIALS: CLAY, CLAY LINER, SILT, SILTSTONE/SHALE

HIGH PERMEABILITY MATERIALS: SAND, SANDSTONE

OTHER: COAL, ASH/CCR

CROSS SECTION LEGEND

EXISTING GROUND (BASED ON SURVEY)

APPROXIMATE EXISTING GROUND (BASED ON SITE OBSERVATIONS AND AERIAL IMAGERY)

APPROXIMATE MATERIAL BOUNDARIES

NOTES

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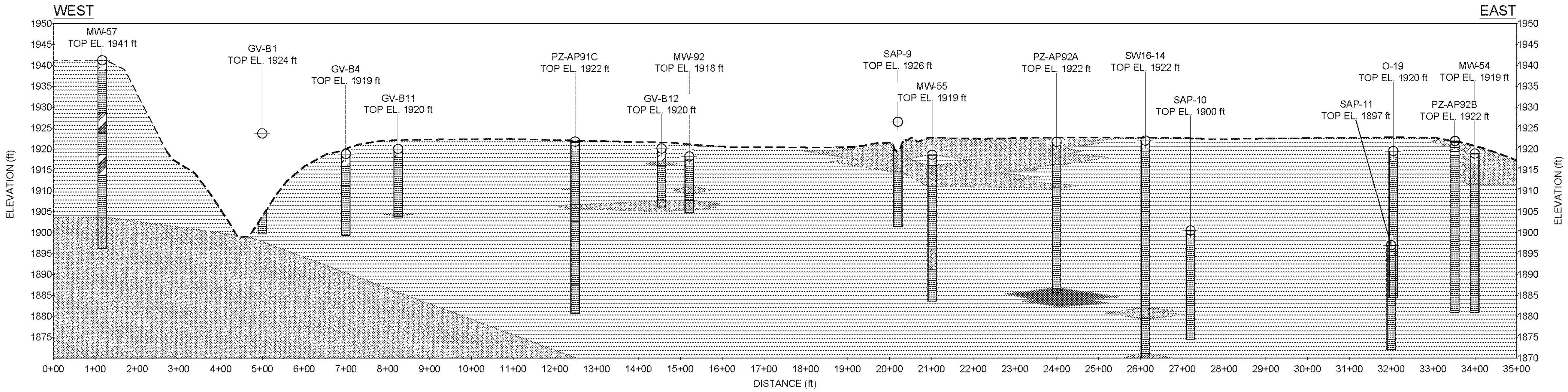
5. LOW PERMEABILITY SOILS ARE GENERALLY EXPECTED TO HAVE SATURATED HYDRAULIC CONDUCTIVITIES LESS THAN $1x10^{-5}$ cm/sec AND HIGH PERMEABILITY SOILS ARE GENERALLY EXPECTED TO HAVE SATURATED HYDRAULIC CONDUCTIVITY GREATER THAN $1x10^{-5}$ cm/sec.
6. EXISTING GROUND, LINER GRADES, AND ASH/CCR GRADES ARE APPROXIMATE.

GOLDER

CROSS SECTION B
MIDDLE - ASH POND 91/92

FIGURE A3



GEOLOGIC LEGEND

LOW PERMEABILITY MATERIALS — CLAY, CLAY LINER, SILT, SILTSTONE/SHALE

HIGH PERMEABILITY MATERIALS — SAND, SANDSTONE

OTHER — COAL, ASH/CCR

CROSS SECTION LEGEND

EXISTING GROUND (BASED ON SURVEY)

APPROXIMATE EXISTING GROUND (BASED ON SITE OBSERVATIONS AND AERIAL IMAGERY)

APPROXIMATE MATERIAL BOUNDARIES

NOTES

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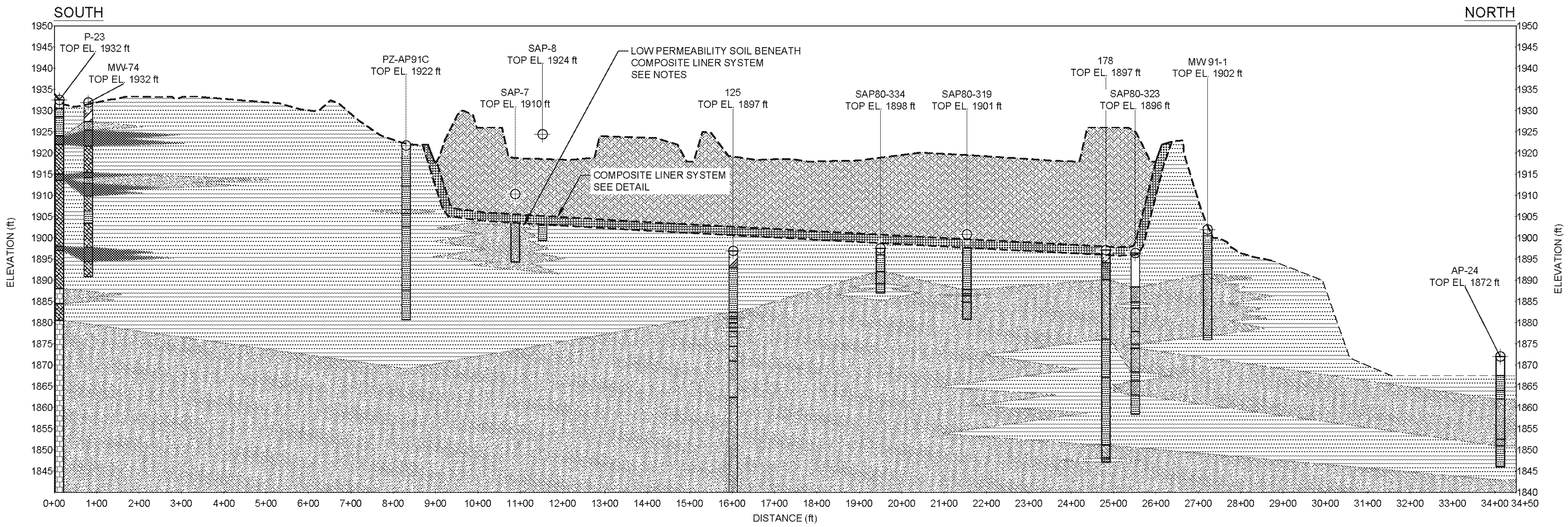
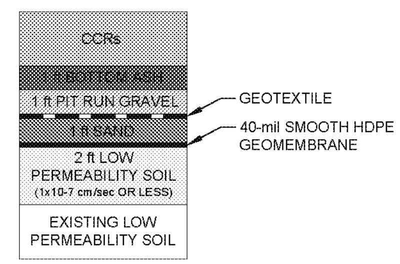
3. MATERIAL BOUNDARIES WERE DRAWN BASED ON BORING INFORMATION AND SITE OBSERVATIONS AND ARE SHOWN FOR INFORMATION ONLY.
4. INFORMATION FROM CONSTRUCTION QUALITY ASSURANCE DOCUMENTATION INDICATES THAT SOME LOCATIONS BELOW THE DESIGN SUBGRADE OF ASH POND 91 AND ASH POND 92 (INCLUDING SAND LENSES) WERE OVER-EXCAVATED AND BACKFILLED WITH LOW PERMEABILITY SOIL PRIOR TO CONSTRUCTION OF THE COMPOSITE LINER SYSTEM.
5. LOW PERMEABILITY SOILS ARE GENERALLY EXPECTED TO HAVE SATURATED HYDRAULIC CONDUCTIVITIES LESS THAN $1x10^{-6}$ cm/sec AND HIGH PERMEABILITY SOILS ARE GENERALLY EXPECTED TO HAVE SATURATED HYDRAULIC CONDUCTIVITY GREATER THAN $1x10^{-5}$ cm/sec.
6. EXISTING GROUND, LINER GRADES, AND ASH/CCR GRADES ARE APPROXIMATE.

GOLDER

CROSS SECTION C
SOUTH SIDE - ASH POND 91/92

FIGURE A4





1 COMPOSITE LINER SYSTEM

GEOLOGIC LEGEND

LOW PERMEABILITY MATERIALS

CLAY, CLAY LINER, SILT, SILTSTONE/ SHALE

HIGH PERMEABILITY MATERIALS

SAND, SANDSTONE

OTHER

COAL, ASH/CCR

CROSS SECTION LEGEND

EXISTING GROUND (BASED ON SURVEY)

APPROXIMATE EXISTING GROUND (BASED ON SITE OBSERVATIONS AND AERIAL IMAGERY)

APPROXIMATE MATERIAL BOUNDARIES

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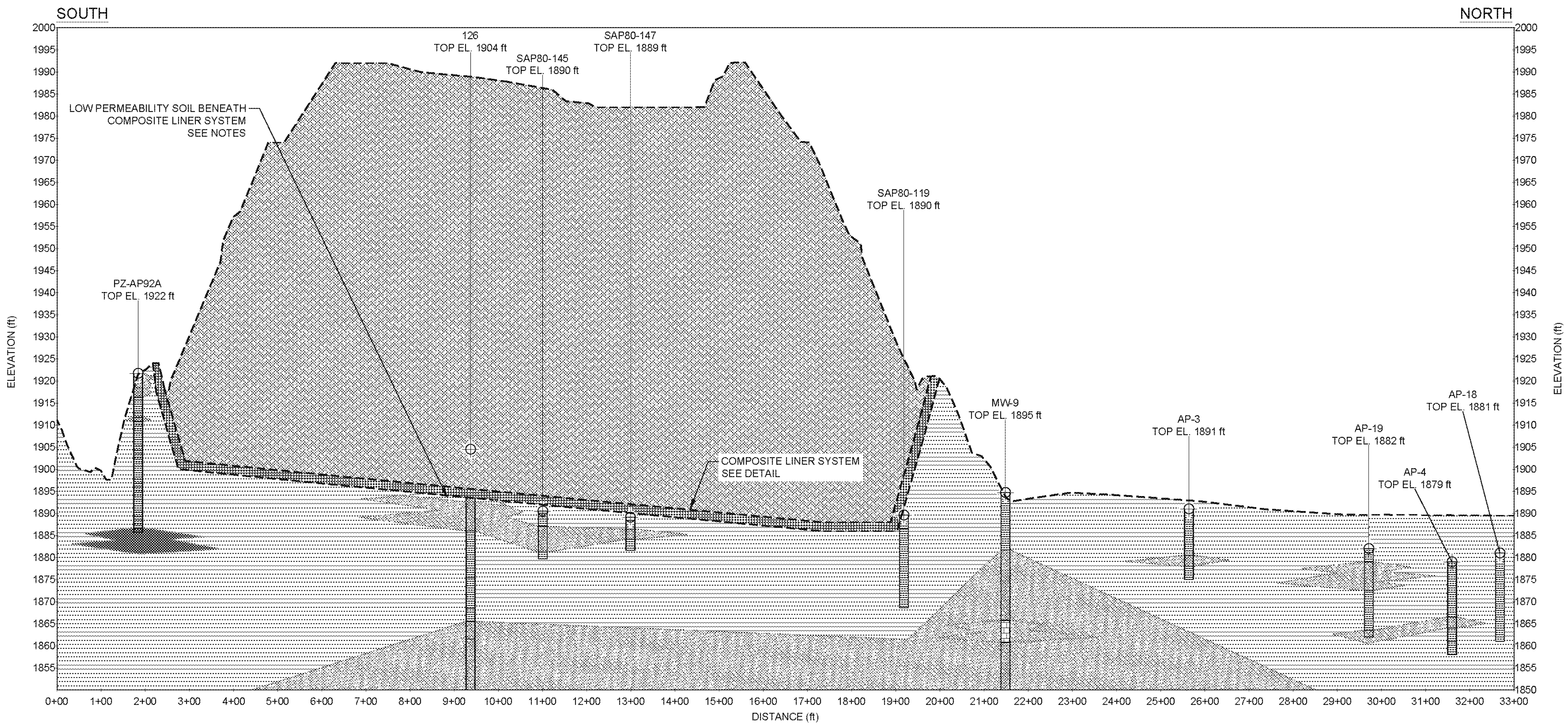
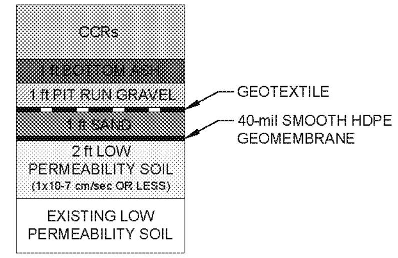
5. LOW PERMEABILITY SOILS ARE GENERALLY EXPECTED TO HAVE SATURATED HYDRAULIC CONDUCTIVITIES LESS THAN $1x10^{-6}$ cm/sec AND HIGH PERMEABILITY SOILS ARE GENERALLY EXPECTED TO HAVE SATURATED HYDRAULIC CONDUCTIVITY GREATER THAN $1x10^{-5}$ cm/sec.
6. EXISTING GROUND, LINER GRADES, AND ASH/CCR GRADES ARE APPROXIMATE.

GOLDER

CROSS SECTION D
ASH POND 91

FIGURE A5





1 COMPOSITE LINER SYSTEM

GEOLOGIC LEGEND

LOW PERMEABILITY MATERIALS — CLAY, CLAY LINER, SILT, SILTSTONE/SHALE

HIGH PERMEABILITY MATERIALS — SAND, SANDSTONE

OTHER — COAL, ASH/CCR

CROSS SECTION LEGEND

EXISTING GROUND (BASED ON SURVEY)

APPROXIMATE EXISTING GROUND (BASED ON SITE OBSERVATIONS AND AERIAL IMAGERY)

APPROXIMATE MATERIAL BOUNDARIES

NOTES

1. BORING INFORMATION IS BASED ON INFORMATION PROVIDED BY GREAT RIVER ENERGY. THE ELEVATIONS OF BORINGS ARE APPROXIMATE AND BORING INFORMATION HAS BEEN PROJECTED TO APPLICABLE SECTIONS.
2. HISTORIC BORINGS MAY BE TRUNCATED AT THE TOP OF LINER OR CURRENT EXISTING GROUND SURFACE GRADES DUE TO CHANGES IN SITE GEOMETRY SINCE BORINGS WERE COMPLETED. BORINGS WITHIN LINED FACILITY BOUNDARIES ARE HISTORIC AND WERE COMPLETED PRIOR TO COMPOSITE LINER CONSTRUCTION.
3. MATERIAL BOUNDARIES WERE DRAWN BASED ON BORING INFORMATION AND SITE OBSERVATIONS AND ARE SHOWN FOR INFORMATION ONLY.
4. INFORMATION FROM CONSTRUCTION QUALITY ASSURANCE DOCUMENTATION INDICATES THAT SOME LOCATIONS BELOW THE DESIGN SUBGRADE OF ASH POND 91 AND ASH POND 92 (INCLUDING SAND LENSES) WERE OVER-EXCAVATED AND BACKFILLED WITH LOW PERMEABILITY SOIL PRIOR TO CONSTRUCTION OF THE COMPOSITE LINER SYSTEM.
5. LOW PERMEABILITY SOILS ARE GENERALLY EXPECTED TO HAVE SATURATED HYDRAULIC CONDUCTIVITIES LESS THAN $1x10^{-6}$ cm/sec AND HIGH PERMEABILITY SOILS ARE GENERALLY EXPECTED TO HAVE SATURATED HYDRAULIC CONDUCTIVITY GREATER THAN $1x10^{-5}$ cm/sec.
6. EXISTING GROUND, LINER GRADES, AND ASH/CCR GRADES ARE APPROXIMATE.

GOLDER

CROSS SECTION E
ASH POND 92

FIGURE A6

GOLDER

THE SITE AERIAL IMAGE IS FROM THE UNITED STATES DEPARTMENT OF AGRICULTURE NATIONAL AGRICULTURE IMAGERY PROGRAM AND WAS ACQUIRED IN 2017. THE LOCATION OF THE AERIAL IMAGE IS APPROXIMATE.

SITE OVERVIEW
LOCATION OF UNDISTURBED SAMPLES FOR IN-SITU PERMEABILITY OF NATIVE SOILS

FIGURE A7

APPENDIX B

Low-Permeability Soil Layer Permeability Testing Results

Table B1: Ash Pond 91 Low-Permeability Soil Layer Permeability Test Results

Sample	Northing (ft)	Easting (ft)	Elevation (ft amsl)	Soil Classification	Hydraulic Conductivity (cm/sec)
CLB-CC-314	37258	40240	1908.1	CH	1.8E-08
CLB-CC-312	37392	40039	1908.4	CH	2.1E-08
CLB-CC-313	37551	39820	1908.7	CH	2.1E-08
CLB-CC-315	37462	40321	1906.4	CH	1.5E-08
CLB-CC-316	37615	40085	1907	CH	4.5E-08
CLB-CC-317	37769	39859	1907	CH	1.5E-08
CLB-CC-318	37610	40413	1905.3	CH	1.4E-08
CLB-CC-320	37734	40211	1905.7	CH	1.1E-08
CLB-CC-325	37315	39973	1909.7	CH	3.4E-08
CLB-CC-326	37180	40330	1908.7	CH	1.5E-08
CLB-CC-327	37335	40463	1907.3	CL	1.9E-08
CLB-CC-328	37387	40190	1908.4	CH	1.7E-08
CLB-CC-329	37422	39979	1909.3	CH	4.6E-08
CLB-CC-330	37622	39849	1908.9	CH	1.4E-08
CLB-CC-331	37573	40097	1908.2	CH	3.7E-08
CLB-CC-332	37526	40337	1907	CH	9.5E-08
CLB-CC-333	37483	40538	1906.4	CH	3.2E-08
CLB-CC-334	37801	39793	1908.4	CH	3.5E-08
CLB-CC-335	37748	40044	1907.5	CH	1.7E-08
CLB-CC-336	37694	40314	1906.4	CH	2.1E-08
CLB-CC-337	37627	40616	1905.1	CL	2.6E-08
CLS-CC-342	38765	40182	1901.3	CL	1.3E-08
CLS-CC-354	38768	40464	1900.9	CL	1.3E-08
CLS-CC-353	38700	41517	1897.5	CL	1.5E-08
CLS-CC-345	38506	41521	1896.8	CL	1.4E-08
CLS-CC-346	38753	41072	1898.5	CL	1.6E-08
CLS-CC-347	38760	40876	1899	CL	1.6E-08
CLS-CC-348	38107	41531	1899.7	CL	1.3E-08
CLS-CC-349	38737	39730	1906.4	CL	2.4E-08
CLS-CC-350	38203	41533	1900.9	CL	1.7E-08
CLS-CC-352	38782	39976	1904.9	CH	1.7E-08
CLS-CC-356	37364	41191	1905	CL	1.0E-08
CLS-CC-357	38768	41169	1900.2	CL	1.0E-08
CLS-CC-358	37595	41397	1904.8	CL	2.9E-08
CLS-CC-359	38587	39725	1910.1	CL	2.3E-08
CLS-CC-360	38781	40561	1906.2	CL	3.7E-08
CLS-CC-361	38783	40474	1908.1	CL	1.2E-08
CLS-CC-362	38784	41471	1905.2	CL	1.3E-08
CLS-CC-364	38676	39706	1914.2	CL	2.4E-08
CLS-CC-365	38598	41552	1909.3	CL	1.3E-08
CLS-CC-366	38400	41556	1909.8	CL	3.0E-08
CLS-CC-367	38777	41376	1906.5	CL	2.4E-08
CLS-CC-369	37726	41533	1911.9	CL	1.0E-08
CLS-CC-371	38001	41572	1916.2	CL	1.0E-08
CLB-CC-392	37258	40993	1904.2	CL	1.5E-08
CLB-CC-393	37412	41139	1902.7	CL	2.7E-08
CLB-CC-394	37364	40927	1904.2	CL	1.1E-08
CLB-CC-395	37493	41045	1902.9	CL	1.1E-08
CLB-CC-396	37972	40399	1903.3	CL	1.4E-08

Table B1: Ash Pond 91 Low-Permeability Soil Layer Permeability Test Results

Sample	Northing (ft)	Easting (ft)	Elevation (ft amsl)	Soil Classification	Hydraulic Conductivity (cm/sec)
CLB-CC-397	38025	40104	1904.6	CL	2.3E-08
CLB-CC-398	38061	39856	1905.9	CL	2.3E-08
CLB-CC-399	37209	40596	1907	CL	1.6E-08
CLB-CC-400	37375	40731	1905.4	CL	1.5E-08
CLB-CC-401	37556	40853	1903.9	CL	1.4E-08
CLB-CC-402	37830	40000	1906.4	CL	3.1E-08
CLB-CC-403	37950	39800	1906.6	CL	1.4E-08
CLB-CC-407	37432	41294	1913.9	CL	1.7E-08
CLB-CC-408	37200	41077	1915.5	CL	1.6E-08
CLB-CC-411	37160	40581	1907.7	CL	2.5E-08
CLB-CC-423	37325	40670	1906.4	SC	2.6E-08
CLB-CC-413	37516	40775	1904.9	CL	1.5E-08
CLB-CC-414	37144	40783	1906.8	CL	1.5E-08
CLB-CC-424	37299	40861	1905.9	CL	1.2E-08
CLB-CC-425	37438	40932	1904.5	CL	1.4E-08
CLB-CC-417	37600	41010	1903.4	CL	9.4E-09
CLB-CC-418	37190	40965	1905.8	CL	1.0E-08
CLB-CC-419	37337	41070	1904.5	CL	1.0E-08
CLB-CC-420	37484	41175	1903.3	CL	1.7E-08
CLB-CC-430	37995	40833	1901.1	CL	1.6E-08
CLB-CC-431	37963	41018	1900.7	CL	1.6E-08
CLB-CC-432	37910	41240	1899.5	CL	1.7E-08
CLB-CC-433	37865	41450	1898.8	CL	1.6E-08
CLB-CC-434	38115	40708	1901.3	CL	2.6E-08
CLB-CC-435	38157	40503	1902.4	CL	1.7E-08
CLB-CC-436	38192	40278	1903.5	CL	1.8E-08
CLB-CC-437	38227	40077	1903.9	CL	1.0E-08
CLB-CC-438	38264	39851	1904.9	CL	2.6E-08
CLB-CC-439	38260	40736	1900	CL	1.2E-08
CLB-CC-440	38288	40543	1901.3	CL	1.5E-08
CLB-CC-441	38322	40332	1902.3	CL	1.8E-08
CLB-CC-442	38353	40125	1903.2	CL	1.5E-08
CLB-CC-443	38391	39895	1904	CL	8.2E-09
CLB-CC-444	37664	41338	1900.3	CL	2.2E-08
CLB-CC-445	37700	41169	1901	CL	3.1E-08
CLB-CC-446	37746	40951	1901.7	CL	1.3E-08
CLB-CC-447	38550	39818	1903.7	CL	1.6E-08
CLB-CC-448	38518	40018	1903.1	CL	1.8E-08
CLB-CC-449	38479	40225	1902.2	CL	1.1E-08
CLB-CC-450	38431	40459	1901.3	CL	1.0E-08
CLB-CC-451	38381	40701	1900.2	CL	1.3E-08
CLB-CC-453	38192	39823	1906.6	CL	1.5E-08
CLB-CC-454	38157	40016	1905.8	CL	1.5E-08
CLB-CC-455	38118	40188	1905	CL	1.2E-08
CLB-CC-456	38079	40385	1904.4	CL	1.9E-08
CLB-CC-457	38040	40587	1904.4	CL	1.4E-08
CLB-CC-458	38136	40645	1902.7	CL	2.6E-08
CLB-CC-459	38184	40402	1903.6	CL	4.7E-08
CLB-CC-460	38220	40218	1904.4	CL	1.7E-08

Table B1: Ash Pond 91 Low-Permeability Soil Layer Permeability Test Results

Sample	Northing (ft)	Easting (ft)	Elevation (ft amsl)	Soil Classification	Hydraulic Conductivity (cm/sec)
CLB-CC-461	38258	40044	1905.2	CL	1.5E-08
CLB-CC-462	38295	39831	1905.9	CL	2.4E-08
CLB-CC-463	38411	39832	1905.2	CL	1.3E-08
CLB-CC-464	38369	40060	1904.4	CL	1.2E-08
CLB-CC-465	38332	40235	1903.7	CL	1.4E-08
CLB-CC-466	38293	40430	1902.8	CL	3.4E-08
CLB-CC-467	38242	40671	1901.9	CL	5.6E-08
CLB-CC-468	37582	41284	1902.3	CL	1.2E-08
CLB-CC-469	37626	41076	1903.1	CL	1.7E-08
CLB-CC-470	37651	40870	1904.1	CL	9.3E-09
CLB-CC-471	37676	40644	1904.9	CL	3.2E-08
CLB-CC-472	37888	40690	1903.7	CL	2.5E-08
CLB-CC-473	38761	40887	1903	CL	2.4E-08
CLB-CC-474	37831	41087	1902.1	CL	1.2E-08
CLB-CC-475	37792	41303	1901.2	CL	1.1E-08
CLB-CC-476	37760	41460	1900.6	CL	1.2E-08
CLB-CC-477	38020	40724	1902.9	CL	1.4E-08
CLB-CC-478	37993	40902	1902.3	CL	1.6E-08
CLB-CC-479	37960	41119	1901.4	CL	1.4E-08
CLB-CC-480	37922	41333	1900.3	CL	1.5E-08
CLB-CC-481	37896	41466	1899.9	CL	1.5E-08
CLB-CC-496	38707	39840	1903.1	CL	4.2E-08
CLB-CC-494	38692	40044	1902.3	CL	3.3E-08
CLB-CC-497	38692	40044	1902.3	CL	4.2E-08
CLB-CC-498	38671	40233	1901.1	CL	4.3E-08
CLB-CC-502	38177	40802	1900.4	CL	2.0E-08
CLB-CC-503	38140	41032	1899.6	CL	2.2E-08
CLB-CC-504	38106	41242	1898.5	SC	2.5E-08
CLB-CC-505	38088	41425	1897.8	CL	2.5E-08
CLB-CC-506	38470	40184	1903.2	CL	9.1E-09
CLB-CC-518	38504	40006	1903.8	CL	1.1E-08
CLB-CC-508	38543	39797	1904.8	CL	2.3E-08
CLB-CC-509	38647	39806	1904.3	CL	6.7E-08
CLB-CC-510	38613	39990	1903.4	SC	2.0E-08
CLB-CC-511	38584	40176	1902.7	CL	1E-07
CLB-CC-512	38567	40518	1900	CL	9.0E-09
CLB-CC-513	38542	40701	1899	CL	3.5E-08
CLB-CC-514	38334	40761	1900	CL	1.8E-08
CLB-CC-515	38309	40956	1898.9	CL	7.9E-09
CLB-CC-516	38283	41112	1898.4	CL	1.9E-08
CLB-CC-517	38253	41287	1897.6	CL	1.1E-08
CLB-CC-519	38450	41412	1896	CL	2.1E-08
CLB-CC-520	38477	41204	1897	CL	1.3E-08
CLB-CC-521	38496	41029	1897.7	CL	1.2E-08
CLB-CC-522	38520	40833	1898.5	CL	8.6E-09
CLB-CC-523	38681	40655	1898.7	SC	3.6E-08
CLB-CC-524	38670	40791	1898.1	CL	1.4E-08
CLB-CC-525	38652	40980	1897.1	CL	1.1E-08
CLB-CC-526	38653	41158	1896.4	CL	4.8E-09

Table B1: Ash Pond 91 Low-Permeability Soil Layer Permeability Test Results

Sample	Northing (ft)	Easting (ft)	Elevation (ft amsl)	Soil Classification	Hydraulic Conductivity (cm/sec)
CLB-CC-527	38619	41340	1895.4	CL	1.2E-08
CLB-CC-533	38509	40197	1903.4	CL	1.5E-08
CLB-CC-534	38474	40419	1902.3	CL	1.8E-08
CLB-CC-535	38431	40626	1901.5	CL	1.3E-08
CLB-CC-536	38391	40844	1900.6	CL	1.6E-08
CLB-CC-537	38356	41054	1899.7	CL	1.5E-08
CLB-CC-538	38322	41252	1898.9	CL	2.6E-08
CLB-CC-539	38294	41436	1898.3	CL	1.1E-08
CLB-CC-540	38177	40733	1902.1	CL	1.9E-08
CLB-CC-541	38144	40930	1901.3	CL	7.4E-09
CLB-CC-542	38114	41132	1900.5	CL	8.2E-09
CLB-CC-543	38082	41346	1899.6	CL	1.1E-08
CLB-CC-544	38492	41401	1896.4	CL	1.7E-08
CLB-CC-545	38512	41211	1898.1	CL	8.3E-09
CLB-CC-546	38548	41001	1898.9	CL	1.5E-08
CLB-CC-547	38577	40790	1900	CL	1.5E-08
CLB-CC-548	38609	40570	1900.7	CL	9.6E-09
CLB-CC-549	38636	40360	1901.7	CL	1.6E-08
CLB-CC-550	38659	40181	1902.3	CL	8.4E-09
CLB-CC-551	38699	41202	1897.2	CL	1.3E-08
CLB-CC-552	38708	40966	1898.4	CL	1.2E-08
CLB-CC-553	38726	40728	1899.4	CL	1.8E-08
CLB-CC-554	38736	40515	1900.5	CL	1.0E-08
				Geometric Mean	1.7E-08

Notes:

Permeability tests performed on undisturbed samples collected from the liner in Shelby tubes.

Permeability results from falling head tests performed by Braun Intertec.

Reference: Cooperative Power Association, 1993 "Final Construction Report, Evaporation Pond 93 and Ash Pond 91"

Table B2: Ash Pond 92 Low-Permeability Soil Layer Permeability Test Results

Sample	Northing (ft)	Easting (ft)	Elevation (ft amsl)	Soil Classification	Hydraulic Conductivity (cm/sec)
1A	38785	42477	1900.8	CH	6.4E-08
2A	38789	42726	1903.4	CH	6.8E-08
3A	38218	42964	1912.8	CH	3.2E-08
4A	37093	42461	1913.7	CH	4.5E-08
5A	37090	42706	1913.6	CH	2.4E-08
6A	37585	42979	1916.8	CH	7.7E-08
7A	38306	41687	1896.5	CH	2.9E-08
8A	38748	41706	1891.4	CH	1.6E-08
11A	38250	41815	1893.3	CH	7.9E-08
12A	37207	42985	1918.6	CH	2.0E-08
13A	37084	42416	1917	CH	5.6E-08
15A	38439	41677		CH	3.9E-08
16B	37338	42889	1903.8	CL	2.2E-08
17A	37658	42890	1901.1	CL	6.0E-08
18A	38450	42350	1889.5	CL	4.0E-08
19A	38050	42350	1893	CL	4.0E-08
20B	37450	42350	1898.1	CL	5.6E-08
22A	38425	42974	1916.3	CH	7.0E-08
23A	37656	42984	1919.7	CH	7.7E-08
25A	38206	41669	1902.4	CH	3.6E-08
26A	38770	41792	1895.5	CH	2.8E-08
27B	38809	42686	1910.7	CH	6.8E-08
28A	38089	42985	1919.9	CH	9.0E-08
29A	37075	42555	1919.7	CH	5.5E-08
30B	38736	41672	1899.7	CL	5.4E-08
32B	38050	42750	1896.1	CL	4.0E-08
33A	38200	42800	1897.5	CL	4.7E-08
34A	37450	41750	1900.9	CL	6.3E-08
35A	37650	41950	1897.4	CL	3.2E-08
36A	37250	41550	1904.4	CL	4.1E-08
38A	38250	41950	1892	CL	5.1E-08
39A	37850	41950	1895.8	CL	3.5E-08
40A	37400	42900	1904.3	CH	7.3E-08
41A	37600	42900	1902.9	CH	7.5E-08
42A	37800	42900	1901.2	CH	4.2E-08
43A	38781	41926	1899.7	CH	6.6E-08
44A	37250	42750	1903.4	CL	3.9E-08
45A	37450	42750	1902	CL	4.0E-08
46B	37650	42750	1900	CL	5.0E-08
47A	37850	42750	1898.3	CL	3.8E-08
48A	37250	42550	1901.7	CL	4.6E-08
49A	37650	42550	1898.4	CL	5.2E-08
50A	37850	42550	1896.6	CL	2.3E-08
51A	38050	42550	1895	CL	5.6E-08
52A	38450	42550	1891.8	CL	7.8E-08
54A	38000	42900	1899.4	CH	4.0E-08
55A	38200	42900	1897.5	CH	7.2E-08
56A	38400	42900	1895.7	CH	6.2E-08
57A	37850	42150	1893	CL	5.1E-08

Table B2: Ash Pond 92 Low-Permeability Soil Layer Permeability Test Results

Sample	Northing (ft)	Easting (ft)	Elevation (ft amsl)	Soil Classification	Hydraulic Conductivity (cm/sec)
58A	37650	42150	1895.4	CL	4.3E-08
59B	37450	42150	1897.2	CL	3.6E-08
60A	37250	42350	1899.3	CL	5.5E-08
62A	37200	42700	1904.3	CH	7.2E-08
64A	37600	42700	1900.8	CH	9.5E-08
66A	38000	42700	1897	CL	3.2E-08
67A	38400	42700	1894	CH	9.3E-08
68A	38600	42700	1892.1	CH	5.9E-08
70B	37400	42500	1901	CH	3.1E-08
71A	37600	42500	1899.1	CH	3.2E-08
72A	38000	42500	1895.8	CH	2.1E-08
74A	38400	42500	1892.3	CH	2.8E-08
76A	38834	42700	1918.6	CH	3.4E-08
77B	38600	42300	1888.3	CH	2.9E-08
79A	38200	42300	1892.3	CH	4.3E-08
82B	37600	42300	1897.5	CH	4.4E-08
85A	38050	42150	1892.6	CH	4.6E-08
88A	37250	41950	1900	CH	3.9E-08
89B	37250	42150	1899.6	CH	3.7E-08
90A	37850	41750	1897.4	CH	3.1E-08
91A	38050	41750	1895.6	CH	9.8E-08
92B	38250	41750	1893.9	CH	2.3E-08
98B	38200	42100	1892.5	CH	1.7E-08
100A	37110	41828	1909.3	CH	4.2E-09
101A	38600	41900	1890.5	CL	3.2E-08
103A	38200	41900	1894.3	CH	1.4E-08
104A	38000	41900	1896	CH	8.3E-09
106A	37400	41900	1900.8	CL	1.8E-08
109A	37220	41636	1914.1	CH	4.7E-08
111A	38825	42167	1917.8	CH	3.2E-08
116A	38450	41750	1892.1	CH	1.5E-08
				Geometric Mean	4.0E-08

Notes:

Permeability tests performed on undisturbed samples collected from the liner in Shelby tubes.
Permeability results from falling head tests performed by Braun Engineering Testing.
Reference: Foth & Van Dyke, 1990. "Construction Observation Report for East Half of South Ash Pond."

APPENDIX C

Geomembrane Liner QA/QC Testing Results

Table C1: AP91 HDPE Conformance Test Results

Roll ID	Thickness (mil)	Tensile Strength Test Method ASTM D638		Elongation Test Method ASTM D638	
		Break (lb/in)	Yield (lb/in)	Break (%)	Yield (%)
6846	45	209	106	797	20
6852	44	212	109	805	21
0697	44	224	121	827	19
0717	43	208	115	827	21
0721	43	213	115	825	20
0729	44	217	121	820	20
6693	43	206	107	830	19
6859	46	212	104	846	19
6862	44	208	110	808	20
6866	47	209	121	786	20
0661	47	227	119	830	20
0665	44	229	117	837	21
0670	46	231	107	852	20
0674	47	239	121	833	21
0683	46	243	117	834	19
0688	47	230	127	814	21
6829	46	203	107	789	21
6833	45	208	111	773	19
6838	47	225	119	823	20
6842	45	216	112	825	20
6871	45	208	111	799	20
6925	44	208	103	820	21
6907	46	219	100	878	20
6912	45	219	108	846	19
6916	46	207	104	831	20
6921	44	211	104	849	20
6939	48	226	116	840	20
6940	47	222	109	826	21
6947	47	224	118	822	20
6952	44	206	105	805	25
0722	43	216	114	833	20
0742	44	218	115	854	20
0747	44	227	116	841	20
0756	44	215	115	814	21
0761	44	225	112	833	20
0765	45	215	113	832	21
0771	43	218	114	825	21
0774	44	209	110	827	21
6821	46	195	114	765	21
6895	45	205	101	836	22
0783	43	209	113	819	19
0787	43	219	110	848	21
0790	44	218	104	823	23
0795	43	223	110	853	21
0800	43	218	104	845	24
6957	46	216	115	815	19
0802	44	207	111	801	20
0814	45	234	114	847	19

Table C1: AP91 HDPE Conformance Test Results

Roll ID	Thickness (mil)	Tensile Strength Test Method ASTM D638		Elongation Test Method ASTM D638	
		Break (lb/in)	Yield (lb/in)	Break (%)	Yield (%)
0816	43	215	112	804	23
0820	43	213	112	809	26
0824	44	228	118	817	25
0828	43	224	119	803	28
0833	43	210	116	791	27
0838	44	226	115	827	25
0840	43	216	115	824	23
0850	43	231	113	854	26
0860	43	211	111	826	28
0862	42	204	112	821	26
6960	45	215	114	802	26
6972	46	234	115	830	21
0874	42	209	109	824	26
0876	43	201	112	802	25
0883	43	216	111	874	20
0888	43	214	113	835	19
0893	44	224	118	828	20
0896	43	215	114	845	20
0899	44	222	115	840	20
0902	42	212	113	833	21
0903	43	213	114	840	20

Notes:

Reference: Cooperative Power Association, 1993 "Final Construction Report, Evaporation Pond 93 and Ash Pond 91"

The break strength, yield strength, break elongation, and yield elongation (ASTM D638) are each an average of one test in the machine direction and one test in the transverse direction.

Table C2: AP91 HDPE Quality Control Certification Test Results

Roll ID	Thickness (mil)	Tensile Strength Test Method ASTM D638		Elongation Test Method ASTM D638		Puncture Resistance Test Method ASTM D1004	Tear Resistance Test Method FTMS 101C 2065
		Break (lb/in)	Yield (lb/in)	Break (%)	Yield (%)	(lbs)	(lbs)
6010659	44	203	142	750	14	89	42
6010662	44	192	141	714	14	90	41
6010663	43	244	120	880	17	89	38
6010667	44	240	130	835	16	84	39
6010669	44	272	152	903	14	83	40
6010671	43	247	139	890	16	89	41
6010674	45	235	127	838	16	88	38
6010677	46	259	132	889	17	83	36
6010689	45	239	129	861	19	89	37
6010704	43	247	136	835	15	81	35
6010706	43	240	134	847	15	84	36
6010714	45	240	138	835	15	89	39
6010716	44	217	134	790	15	90	39
6010718	43	233	126	864	15	89	39
6010721	43	228	120	855	15	88	34
6010722	43	222	114	856	17	85	36
6010728	44	257	134	919	16	89	37
6010729	43	244	129	888	16	86	38
6010746	43	239	133	851	14	78	38
6010756	43	236	144	830	15	86	39
6010766	43	226	130	831	17	83	38
6010774	43	220	130	785	16	85	36
6010776	43	222	120	828	16	83	37
6010787	42	222	119	833	17	84	39
6010789	43	226	130	791	16	67	38
6010791	43	215	115	817	15	82	39
6010793	42	214	127	770	15	81	37
6010795	42	221	125	807	15	84	37
6010797	43	228	134	800	15	83	37
6010799	41	199	113	775	15	86	37
6010800	43	216	117	819	17	88	35
6010802	43	206	117	786	16	82	40
6010804	42	215	123	784	16	92	36
6010806	43	220	133	761	16	88	37
6010808	43	233	132	829	15	87	38
6010810	44	239	132	811	15	85	38
6010812	43	208	127	762	17	94	34
6010814	44	218	127	766	17	83	33
6010816	43	213	129	784	17	86	35
6010818	44	222	138	753	16	91	36
6010820	43	186	133	726	15	89	36
6010822	43	208	133	716	15	92	36
6010824	45	201	124	740	17	78	34
6010826	43	192	122	725	16	80	34
6010828	44	253	128	878	15	74	39

Table C2: AP91 HDPE Quality Control Certification Test Results

Roll ID	Thickness (mil)	Tensile Strength Test Method ASTM D638		Elongation Test Method ASTM D638		Puncture Resistance Test Method ASTM D1004	Tear Resistance Test Method FTMS 101C 2065
		Break (lb/in)	Yield (lb/in)	Break (%)	Yield (%)	(lbs)	(lbs)
6010830	42	216	130	792	15	88	38
6010832	43	228	136	812	15	75	39
6010835	43	242	133	855	15	76	39
6010836	43	228	115	889	15	85	39
6010838	43	187	122	764	16	100	37
6010840	42	211	117	833	16	84	38
6010842	45	263	144	861	15	90	40
6010844	45	230	127	900	15	91	39
6010846	44	238	133	893	16	86	39
6010848	44	243	124	894	17	88	37
6010850	43	235	124	887	17	74	33
6010852	43	226	119	880	16	76	37
6010854	44	240	134	905	17	83	37
6010856	44	245	135	919	15	87	39
6010858	44	230	124	896	16	88	40
6010860	42	203	119	792	16	85	35
6010863	44	229	114	858	17	89	35
6010864	43	234	120	895	16	85	36
6010868	43	212	120	860	16	83	38
6010870	41	228	119	915	16	88	39
6010877	43	209	124	774	18	91	47
6010878	43	209	125	770	16	86	37
6010884	42	215	127	806	16	97	37
6010885	43	223	122	825	15	87	34
6010888	43	186	121	710	16	83	32
6010889	43	183	124	702	16	83	32
6010894	43	203	126	760	16	87	36
6010895	43	198	124	740	16	90	36
6010899	43	227	122	846	16	88	36
7006822	45	222	152	772	14	93	44
7006826	45	239	121	868	16	78	39
7006829	46	237	118	859	17	89	37
7006834	44	210	142	764	15	86	40
7006839	44	216	111	847	17	72	41
7006865	44	242	118	894	16	87	37
7006867	45	229	128	804	16	88	37
7006871	45	231	118	846	17	87	37
7006926	43	225	129	810	16	89	37
7006928	43	211	118	798	17	86	38
7006938	45	229	124	798	15	91	40
7006940	45	202	130	716	15	90	40
7006942	44	231	131	792	15	90	37
7006944	45	228	134	767	14	89	38
7006946	45	227	131	789	15	93	38
7006948	45	211	114	802	15	91	38

Table C2: AP91 HDPE Quality Control Certification Test Results

Roll ID	Thickness (mil)	Tensile Strength		Elongation		Puncture Resistance	Tear Resistance
		Test Method ASTM D638		Test Method ASTM D638		Test Method ASTM D1004	Test Method FTMS 101C 2065
		Break (lb/in)	Yield (lb/in)	Break (%)	Yield (%)	(lbs)	(lbs)
7006950	44	216	113	826	17	88	37
7006952	43	221	127	790	15	90	38
7006954	44	236	127	811	14	85	37
7006958	44	241	133	809	15	90	37
7006959	43	192	115	740	16	82	35
7006961	43	202	120	718	15	74	35
7006963	44	207	130	701	14	89	38
7006965	44	204	130	709	14	89	38
7006967	43	209	130	723	14	88	38
7006969	44	189	118	718	16	92	39
7006971	44	200	122	746	15	86	34
7006973	44	251	128	862	16	85	40
907931	42	213	122	816	16	90	37
907932	40	201	122	801	16	80	35

Notes:
Reference: Cooperative Power Association, 1993 "Final Construction Report, Evaporation Pond 93 and Ash Pond 91"

Table C3: AP92 HDPE Quality Control Certification Test Results

Roll ID	Thickness (mil)	Tensile Strength		Elongation		Puncture Resistance	Tear Strength
		Test Method ASTM D638		Test Method ASTM D638		Test Method ASTM D1004	Test Method FTMS 101C 2065
		Break (lb/in)	Yield (lb/in)	Break (%)	Yield (%)	(lbs)	(lbs)
204	41	198	94	918	16	61	35
207	41	214	103	899	18	66	36
210	43	217	97	917	20	69	38
213	43	219	102	913	18	68	34
216	41	206	106	867	18	67	38
219	42	210	97	976	18	68	35
222	41	216	97	959	19	66	35
225	42	181	93	867	18	63	32
228	41	196	93	926	18	62	32
231	41	198	90	915	18	61	31
234	40	192	90	955	19	60	29
237	41	193	91	931	18	60	30
240	41	208	96	938	16	61	32
243	42	184	90	914	18	60	29
246	42	217	92	963	16	60	29
249	42	209	94	935	19	61	31
252	40	180	90	857	21	61	33
255	41	202	91	925	19	64	33
258	43	195	98	847	18	61	35
261	44	196	90	912	21	60	32
264	43	194	90	934	19	64	33
267	42	180	95	828	27	69	38
270	42	156	83	772	27	63	29
273	43	230	105	932	22	70	37
276	43	213	102	895	24	67	39
279	42	205	102	862	23	63	36
282	42	191	95	849	22	68	33
285	43	207	101	865	24	65	37
288	43	202	95	872	23	61	34
291	43	216	93	898	26	62	33
294	42	223	95	921	22	64	35
297	42	196	100	822	26	60	33
300	43	200	99	829	26	63	37
303	42	191	101	802	23	63	37
306	41	196	91	888	26	60	34
309	42	188	93	828	27	63	31
312	42	177	95	801	26	60	33
315	43	172	90	837	27	62	31
318	43	191	98	829	27	69	34
321	43	187	103	836	33	62	34
324	40	171	97	879	29	65	33
327	43	176	100	826	30	65	35
330	44	164	94	790	30	61	31
333	43	193	107	852	32	61	32
336	43	191	93	751	30	61	34
339	43	175	97	758	27	61	31

Table C3: AP92 HDPE Quality Control Certification Test Results

Roll ID	Thickness (mil)	Tensile Strength Test Method ASTM D638 Break (lb/in)	Tensile Strength Test Method ASTM D638 Yield (lb/in)	Elongation Test Method ASTM D638 Break (%)	Elongation Test Method ASTM D638 Yield (%)	Puncture Resistance Test Method ASTM D1004 (lbs)	Tear Strength Test Method FTMS 101C 2065 (lbs)
342	44	172	98	806	29	62	34
345	42	179	99	724	27	61	33
348	43	178	93	831	28	61	32
351	43	187	90	870	26	61	31
354	42	187	91	854	29	60	30
357	43	175	91	858	27	61	33
360	42	184	90	853	27	62	31
363	44	203	98	881	26	61	36
366	42	197	90	919	29	61	31
369	43	176	90	872	27	68	35
372	42	203	96	899	24	66	36
375	43	198	94	880	24	63	36
378	43	201	95	892	23	64	35
381	42	173	93	810	24	63	32
384	42	207	105	863	21	64	35
387	42	184	96	800	25	67	35
390	42	209	101	903	23	66	34
393	41	215	98	940	24	66	36
396	42	184	101	811	24	63	33
399	42	215	102	907	24	62	33
402	41	214	111	822	25	63	36
405	41	193	106	821	24	63	35
408	42	207	103	901	23	69	35
411	43	215	116	845	25	61	41
414	43	206	99	890	27	60	36
417	42	212	115	846	20	67	37
420	42	180	95	823	25	65	34
423	42	218	110	869	23	69	40
426	42	177	95	785	23	65	34
429	43	192	110	819	26	61	37
436	43	180	100	775	19	61	36
448	44	179	94	787	19	64	35
454	42	185	103	780	20	71	35
460	44	209	107	753	18	66	40
466	41	187	103	754	20	61	38
468	41	190	107	777	20	62	34
478	42	166	103	760	20	62	34
480	45	218	121	792	20	84	46
484	43	213	112	783	20	69	39

Notes:
Reference: Foth & Van Dyke, 1990. "Construction Observation Report for East Half of South Ash Pond."

Table C4: AP91 HDPE Field Seam Destructive Test Results

Sample ID	Shear Strength	Peel Strength
	Test Method ASTM D638	
	(lb/in)	(lb/in)
DSE-1A	128	91
DSE-1B	119	99
DSE-2	124	82
DSE-3	125	85
DS-1	129	79
DS-2A	136	95
DS-2B	122	88
DS-3	120	86
DS-4	124	86
DS-5	118	96
DS-6	129	94
DS-7A	126	89
DS-7B	127	97
DS-8	125	85
DS-9	122	90
DS-10	128	82
DS-11	119	84
DS-12	118	84
DS-13	121	78
DS-14	119	83
DS-15	126	91
DS-16	131	79
DS-17	113	93
DS-18	123	81
DS-19	136	87
DS-20	124	77
DS-21	126	83
DS-22	127	89
DS-23	122	83
DS-24	128	83
DS-25	126	91
DS-26	126	90
DS-27	126	83
DS-28	132	79
DS-29	131	82
DS-30	132	91
DS-31	134	94
DS-32	131	82
DS-33	127	82
DS-34A	116	74
DS-34B	117	78
DS-35	128	84
DS-36	125	68
DS-37	125	80
DS-38	125	80

Table C4: AP91 HDPE Field Seam Destructive Test Results

Sample ID	Shear Strength	Peel Strength
	Test Method ASTM D638	
	(lb/in)	(lb/in)
DS-39	129	86
DS-40	125	81
DS-41	127	76
DS-42	126	80
DS-43	130	83
DS-44	133	84
DS-45	127	79
DS-46	125	88
DS-47	129	86
DS-48	124	85
DS-49	126	87
DS-50	124	98
DS-51	121	79
DS-52	121	85
DS-53	124	79
DS-54	122	82
DS-55	123	87
DS-56	123	85
DS-57	126	96
DS-58	119	78
DS-59	123	87
DS-60	119	84
DS-61	118	79
DS-62	135	88
DS-63	132	91
DS-64	128	86
DS-65	133	88
DS-66	128	90
DS-67	124	91
DS-68	131	95
DS-69	132	75
DS-70	132	84
DS-71	127	78
DS-72	128	86
DS-73	129	76
DS-74	132	85
DS-75	129	82
DS-76	134	80
DS-77	135	89
DS-78	130	88
DS-79	128	90
DS-80	129	96
DS-81	134	88
DS-82	133	77
DS-83	130	78
DS-84	132	95
DS-85	130	85
DS-86	132	99
DS-87	131	87

Table C4: AP91 HDPE Field Seam Destructive Test Results

Sample ID	Shear Strength	Peel Strength
	Test Method ASTM D638	
	(lb/in)	(lb/in)
DS-88	136	91
DS-89	141	80
DS-90	137	99
DS-91	123	84
DS-92	127	95
DS-93	135	89
DS-94	131	86
DS-95	132	98
DS-96	130	93
DS-97	127	93
DS-98	130	86
DS-99	128	85
DS-100	132	87
DS-101	126	80
DS-102	136	89
DS-103	127	86
DS-104	132	99
DS-105	124	92
DS-106	133	99
DS-107	122	96
DS-108	127	92
DS-109	133	91
DS-110	132	93
DS-111	132	94
DS-112	125	86
DS-113	126	92
DS-114	123	80
DS-115	129	80
DS-116	129	76
DS-117	124	92
DS-118	128	81
DS-119	125	71
DS-120	131	89
DS-121	126	69
DS-122A	127	99
DS-122B	132	94
DS-123	128	81
DS-124	127	86
DS-125	122	93
DS-126	125	83
DS-127	130	89
DS-128	128	91
DS-129	126	83
DS-130	129	82
DS-131	130	85
DS-132	131	81
DS-133	133	85
DS-134	134	84
DS-135	131	85

Table C4: AP91 HDPE Field Seam Destructive Test Results

Sample ID	Shear Strength	Peel Strength
	Test Method ASTM D638	
	(lb/in)	(lb/in)
DS-136	135	90
DS-137	131	96
DS-138	129	87
DS-139	130	89
DS-140	130	87
DS-141	133	93
DS-142	133	84
DS-143	132	86
DS-144A	119	102
DS-144B	128	86
DS-145	124	86
DS-146	127	100
DS-147	130	84
DS-148	131	93
DS-149	120	90
DS-150	128	96
DS-151	128	79
DS-152	132	89
DS-153	121	92
DS-154	131	80
DS-155	130	85
DS-156	131	86
DS-157	125	94
DS-158	126	79
DS-159	131	82
DS-160	127	73
DS-161	130	80
DS-162	138	99
DS-163	131	98
DS-164	133	103
DS-165	136	93
DS-166	125	80
DS-167	127	77
DS-168	120	100
DS-169	127	79
DS-170	125	85
DS-171	126	79
DS-172	127	85
DS-173	132	83
DS-174	132	88
DS-175	125	79
DS-176	131	82
DS-177	132	82
DS-178	123	87
DS-179	122	86
DS-180	119	87
DS-181	133	93
DS-182	131	89
DS-183	132	87

Table C4: AP91 HDPE Field Seam Destructive Test Results

Sample ID	Shear Strength	Peel Strength
	Test Method ASTM D638	
	(lb/in)	(lb/in)
DS-184	124	85
DS-185	123	87
DS-186	113	88
DS-187	126	78
DS-188	121	88
DS-189	125	79
DS-190	121	78
DS-191	117	76
DS-192	120	71
DS-193	112	75
DS-194	117	88
DS-195	119	91
DS-196	122	82
DS-197	113	73
DS-198	118	73
DS-199	113	77
DS-200	116	83
DS-201	124	66
DS-202	123	84
DS-203	123	76
DS-204	123	78
DS-205	122	73
DS-206	123	81
DS-207	124	80

Notes:

Reference: Cooperative Power Association, 1993 "Final Construction Report, Evaporation Pond 93 and Ash Pond 91"

The shear and peel strengths shown are each an average of five tests (ASTM D638).

Table C5: AP92 HDPE Field Seam Destructive Test Results

Sample ID	Shear Strength	Peel Strength
	Test Method ASTM D638	
	(lb/in)	(lb/in)
DT-1	105	83
DT-2	112	86
DT-3	103	79
DT-4	106	75
DT-5	101	81
DT-6	105	95
DT-7	109	72
DT-8	109	92
DT-9	107	82
DT-10	103	75
DT-11	117	98
DT-12	106	84
DT-13	108	85
DT-14	105	84
DT-15	103	83
DT-16	99	73
DT-17	105	90
DT-18	103	89
DT-19	111	81
DT-20	103	84
DT-21	100	92
DT-22	100	87
DT-23	105	83
DT-24	98	89
DT-25	99	85
DT-27	112	83
DT-28	106	90
DT-29	109	86
DT-30	109	75
DT-31	109	82
DT-32	109	85
DT-33	102	85
DT-34	109	86
DT-36	103	74
DT-37	112	81
DT-38	107	84
DT-39	105	83
DT-40	102	88
DT-41	108	91
DT-42	106	86
DT-43	107	87
DT-44	114	88
DT-45	103	86
DT-46	112	85
DT-47	113	90

Table C5: AP92 HDPE Field Seam Destructive Test Results

Sample ID	Shear Strength	Peel Strength
	Test Method ASTM D638	
	(lb/in)	(lb/in)
DT-48	104	87
DT-49	105	89
DT-50	102	85
DT-51	100	84
DT-52	106	79
DT-53	100	81
DT-54	100	84
DT-55	102	89
DT-56	104	86
DT-57	104	83
DT-58	108	85
DT-59	104	87
DT-60	117	86
DT-61	101	89
DT-62	123	94
DT-63	122	93
DT-64	109	91
DT-65	95	88
DT-66	103	83
DT-67	105	86
DT-68	101	86
DT-69	105	85
DT-70	103	88
DT-71	99	93
DT-72	105	86
DT-73	107	89
DT-74	105	89
DT-75	105	82
DT-76	102	81
DT-77	100	84
DT-78	101	81
DT-79	109	82
DT-80	102	79
DT-81	107	85
DT-82	106	79
DT-83	100	72
DT-84	103	86
DT-85	111	85
DT-86	105	85
DT-87	102	79
DT-88	113	81
DT-89	105	73
DT-90	109	77
DT-91	111	81
DT-92	106	87
DT-93	108	85
DT-94	99	79
DT-95	101	83
DT-96	103	75

Table C5: AP92 HDPE Field Seam Destructive Test Results

Sample ID	Shear Strength	Peel Strength
	Test Method ASTM D638	
	(lb/in)	(lb/in)
DT-97	106	84
DT-98	94	82
DT-99	111	78
DT-100	110	75
DT-101	103	80
DT-102	109	82
DT-103	102	81
DT-104	108	85
DT-106	100	86
DT-107	105	84
DT-108	92	81
DT-109	99	71
DT-110	98	82
DT-111	105	84
DT-112	106	74
DT-113	96	71
DT-114	107	78
DT-115	106	85
DT-116	98	80
DT-119	109	86
DT-120	103	85
DT-121	85	76
DT-122	106	87
DT-123	118	85
DT-124	108	85
DT-125	100	85
DT-126	100	83
DT-127	108	87
DT-128	101	83
DT-129	106	89
DT-130	104	81
DT-131	102	90
DT-132	112	81
DT-133	106	80
DT-134	108	81
DT-135	107	89
DT-136	106	81
DT-137	109	85
DT-138	108	83
DT-139	108	87
DT-140	107	85
DT-141	99	82
DT-142	102	77
DT-143	94	87
DT-144	99	84
DT-145	102	82
DT-146	103	90
DT-147	107	79
DT-148	107	72

Table C5: AP92 HDPE Field Seam Destructive Test Results

Sample ID	Shear Strength	Peel Strength
	Test Method ASTM D638	
	(lb/in)	(lb/in)
DT-149	103	79
DT-150	105	85
DT-151	104	83
DT-152	106	85
DT-153	110	82
DT-154	104	82
DT-155	101	80
DT-156	109	79
DT-157	85	79
DT-158	107	94
DT-159	106	73
DT-161	100	75
DT-162	98	81
DT-163	102	86
DT-164	98	81
DT-165	100	81
DT-166	108	80
DT-167	108	87
DT-168	103	78
DT-169	99	85
DT-170	105	80
DT-171	100	87
DT-172	101	83
DT-173	102	81
DT-174	103	81
DT-175	104	80
DT-176	107	88
DT-177	111	80
DT-178	104	86
DT-179	99	85
DT-180	84	81
DT-181	112	72
DT-182	107	82
DT-183	105	84
DT-184	109	82
DT-185	101	81
DT-186	103	82
DT-187	101	77
DT-188	102	69
DT-189	101	85
DT-190	101	84
DT-191	105	86
DT-192	102	77
DT-193	105	83
DT-194	107	89
DT-195	102	86
DT-196	117	97
DT-197	116	93
DT-198	120	92

Table C5: AP92 HDPE Field Seam Destructive Test Results

Sample ID	Shear Strength	Peel Strength
	Test Method ASTM D638	
	(lb/in)	(lb/in)
DT-199	117	90
DT-200	117	90
DT-201	107	84
DT-202	113	92
DT-203	107	82
DT-204	125	95
DT-205	107	96
DT-206	127	96
DT-207	117	96
DT-208	112	91
DT-209	144	107
DT-210	113	95
DT-211	121	93
DT-212	136	99
DT-213	142	91
DT-214	143	103
DT-215	120	95
DT-216	124	92
DT-217	110	81
DT-218	124	88
DT-219	113	88
DT-220	93	86
DT-221	108	86
DT-222	106	85
DT-223	114	84
DT-224	121	99
DT-225	116	101
DT-226	98	91
P759-A	105	70
P759-B	111	75

Notes:

Reference: Foth & Van Dyke, 1990. "Construction Observation Report for East Half of South Ash Pond."

The shear and peel strengths shown are each an average of five to ten tests (ASTM D638).

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